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Maloney et al.

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(45) **Date of Patent: Nov. 27, 2001**

(54) **FRAGMENTED APERTURE ANTENNAS AND BROADBAND ANTENNA GROUND PLANES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/579,560**

(22) Filed: **May 26, 2000**

Related U.S. Application Data

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(51) **Int. Cl.**[7] **H01Q 1/38**

(52) **U.S. Cl.** .... **343/700 MS**; 343/846

(58) **Field of Search** .... 343/700 MS, 846, 343/844, 853, 829, 770

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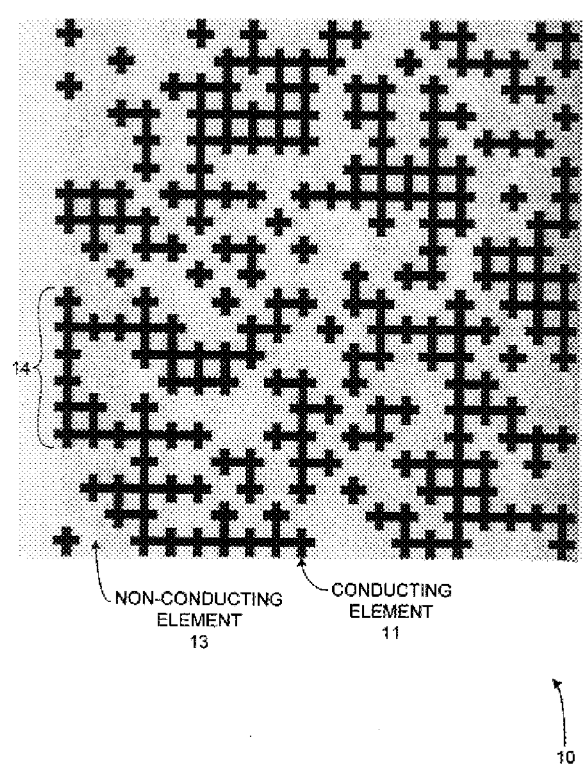
(57) **ABSTRACT**

The present invention provides a fragmented aperture antenna. The antenna includes a planar layer having a plurality of conductive and substantially non-conductive areas. Each area has a periphery that extends along a grid of first and second sets of parallel lines so that each area comprises one or more contiguous elements defined by the parallel lines. The locations of the conducting materials in the fragmented aperture antenna are determined by a multi-stage optimization procedure that tailors the performance of the antenna to a particular application. The resulting configuration and arrangement of conductive and substantially non-conductive areas enable communication of electromagnetic energy wirelessly in a specific direction to the planar layer when an electrical connection is made to at least one of the conductive areas.

35 Claims, 31 Drawing Sheets

RANDOM PATTERN OF CONDUCTING AND NON-CONDUCTING ELEMENTS.



RANDOM PATTERN OF CONDUCTING AND NON-CONDUCTING ELEMENTS.

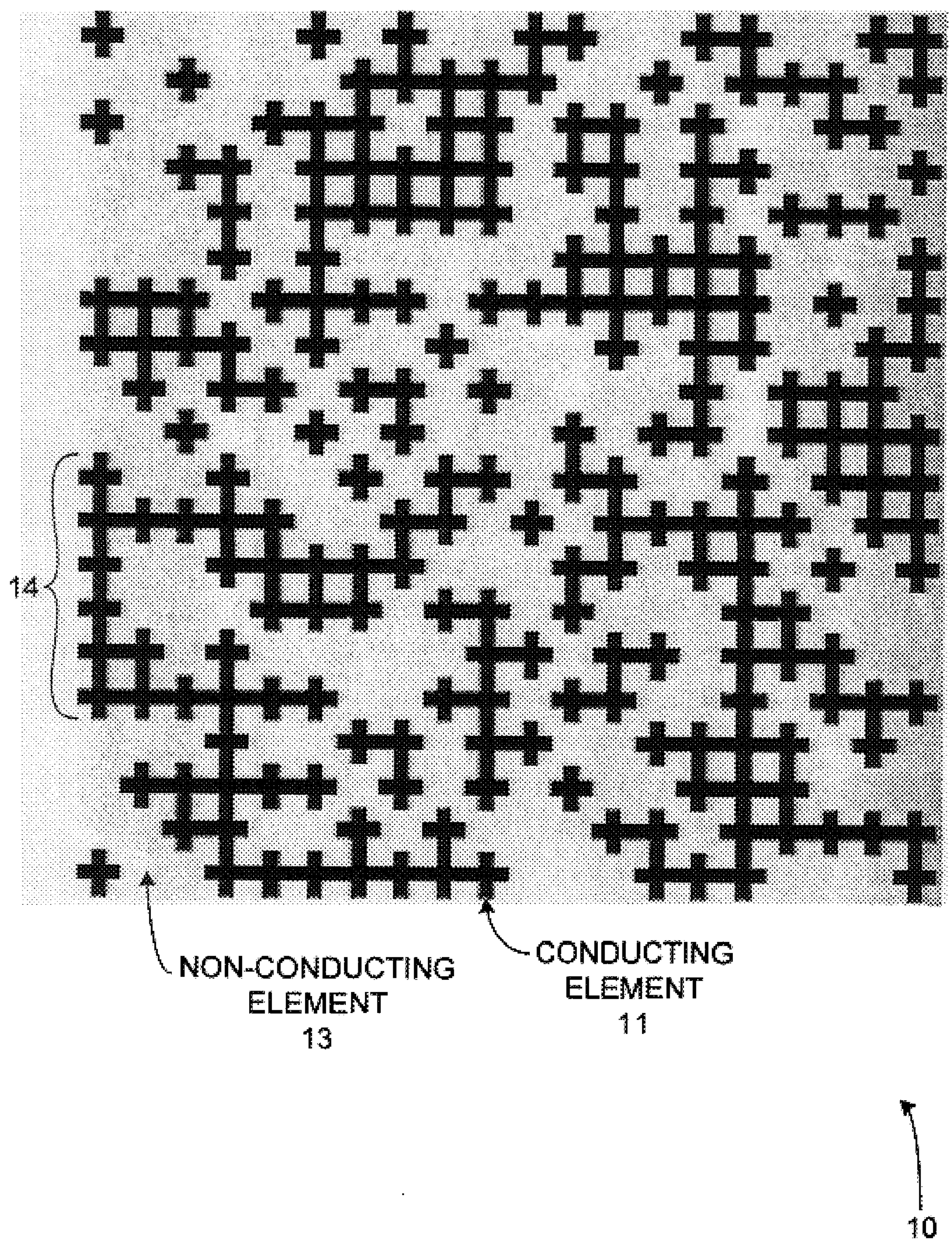
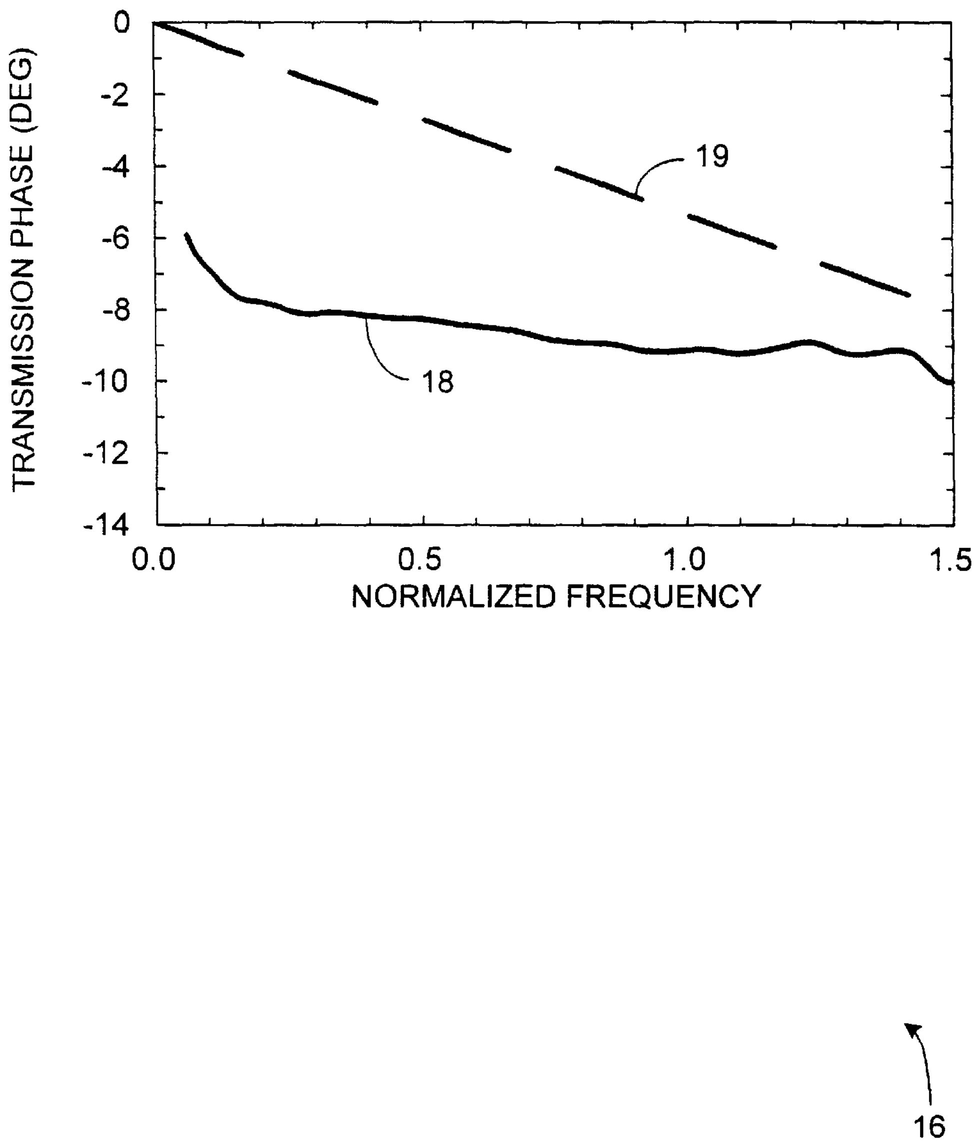


FIG. 1



0
-2
-4
-6
-8
-10
-12
-14
TRANSMISSION PHASE (DEG)
0.0
0.5
1.0
1.5
NORMALIZED FREQUENCY
19
18
16

FIG. 2

FRAGMENTED ATENNA APERTURE OPTIMIZED TO OPERATE
FROM 800 MHZ TO 2.5 GHZ SYSTEM GAIN

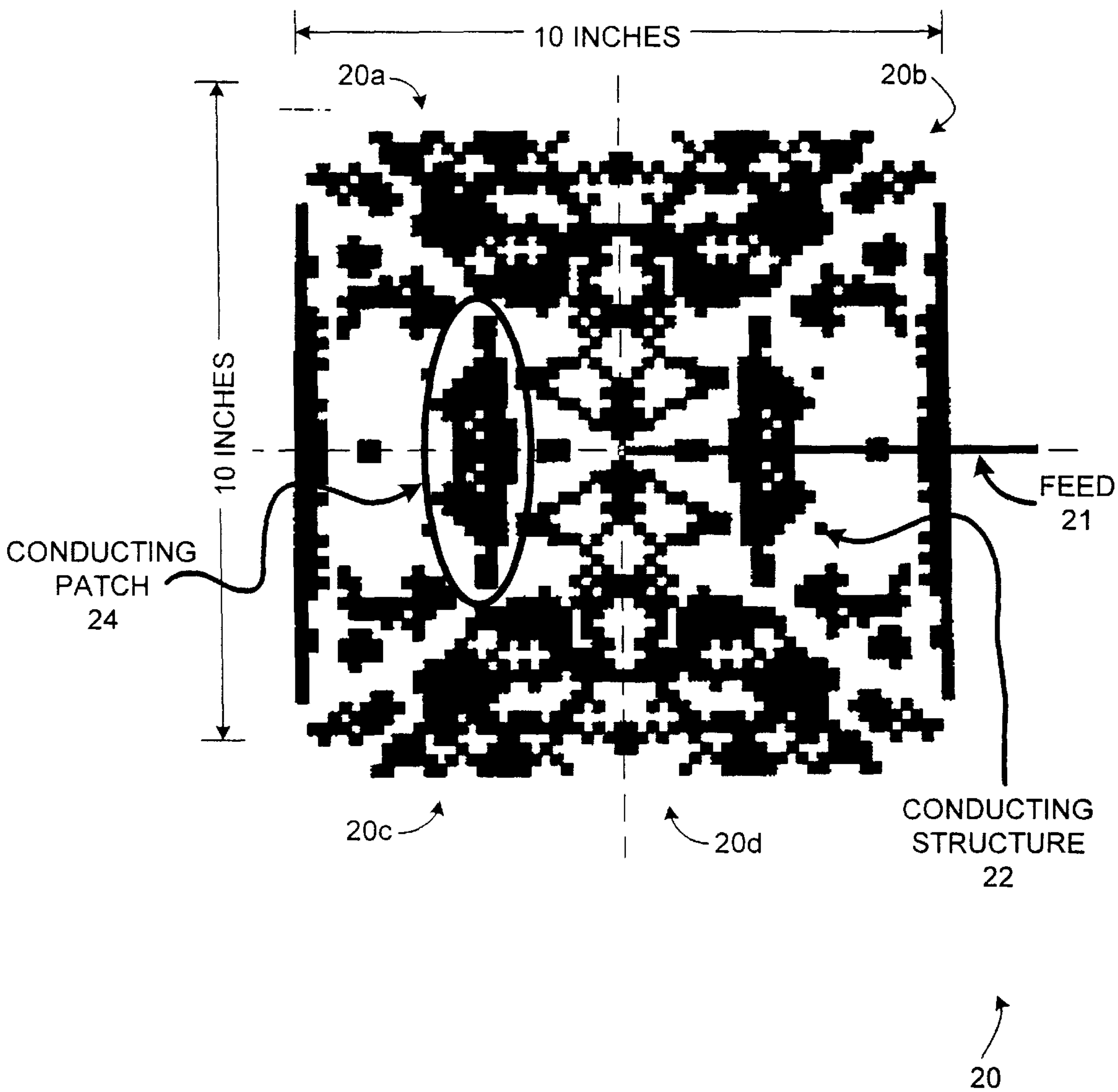


FIG. 3

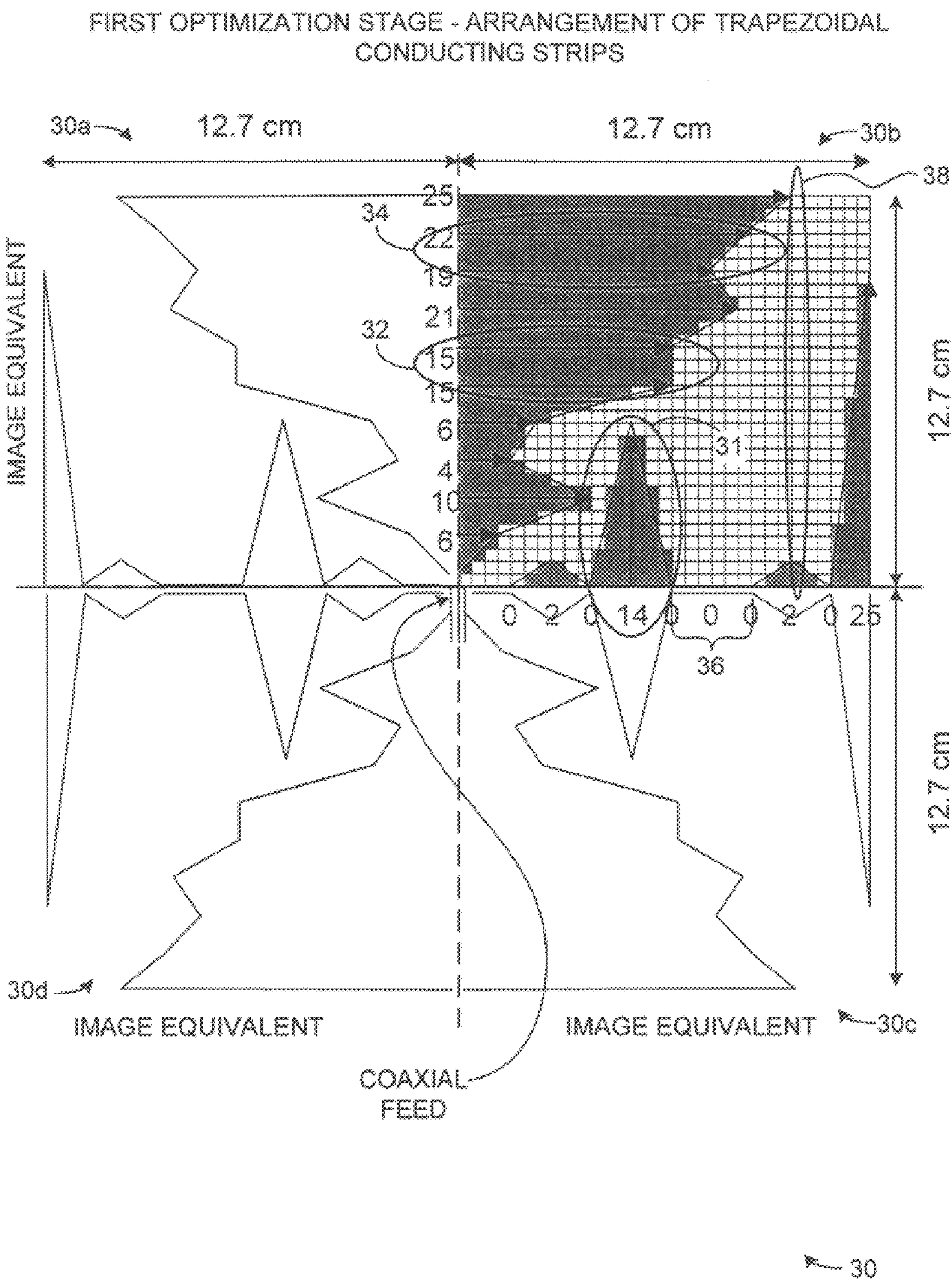

FIRST OPTIMIZATION STAGE - ARRANGEMENT OF TRAPEZOIDAL CONDUCTING STRIPS
30a
12.7 cm
12.7 cm
30b
38
25
22
19
21
15
15
6
4
10
6
34
32
31
IMAGE EQUIVALENT
12.7 cm
0 2 0 14 0 0 0 2 0 25
36
12.7 cm
30d
IMAGE EQUIVALENT
IMAGE EQUIVALENT
30c
COAXIAL FEED
30

FIG. 4

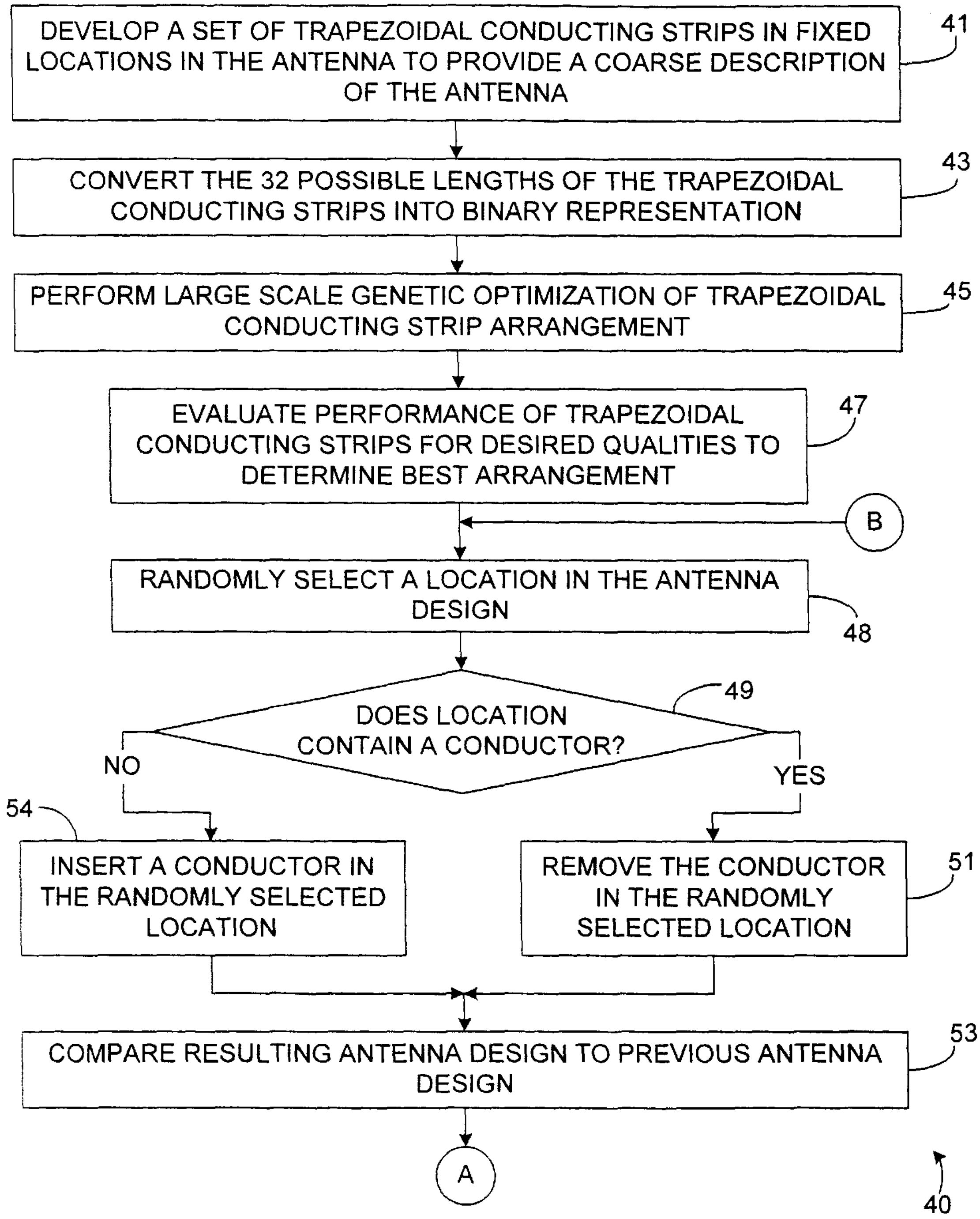

DEVELOP A SET OF TRAPEZOIDAL CONDUCTING STRIPS IN FIXED LOCATIONS IN THE ANTENNA TO PROVIDE A COARSE DESCRIPTION OF THE ANTENNA
41
CONVERT THE 32 POSSIBLE LENGTHS OF THE TRAPEZOIDAL CONDUCTING STRIPS INTO BINARY REPRESENTATION
43
PERFORM LARGE SCALE GENETIC OPTIMIZATION OF TRAPEZOIDAL CONDUCTING STRIP ARRANGEMENT
45
EVALUATE PERFORMANCE OF TRAPEZOIDAL CONDUCTING STRIPS FOR DESIRED QUALITIES TO DETERMINE BEST ARRANGEMENT
47
B
RANDOMLY SELECT A LOCATION IN THE ANTENNA DESIGN
48
DOES LOCATION CONTAIN A CONDUCTOR?
49
NO
YES
54
INSERT A CONDUCTOR IN THE RANDOMLY SELECTED LOCATION
REMOVE THE CONDUCTOR IN THE RANDOMLY SELECTED LOCATION
51
COMPARE RESULTING ANTENNA DESIGN TO PREVIOUS ANTENNA DESIGN
53
A
40

FIG. 5

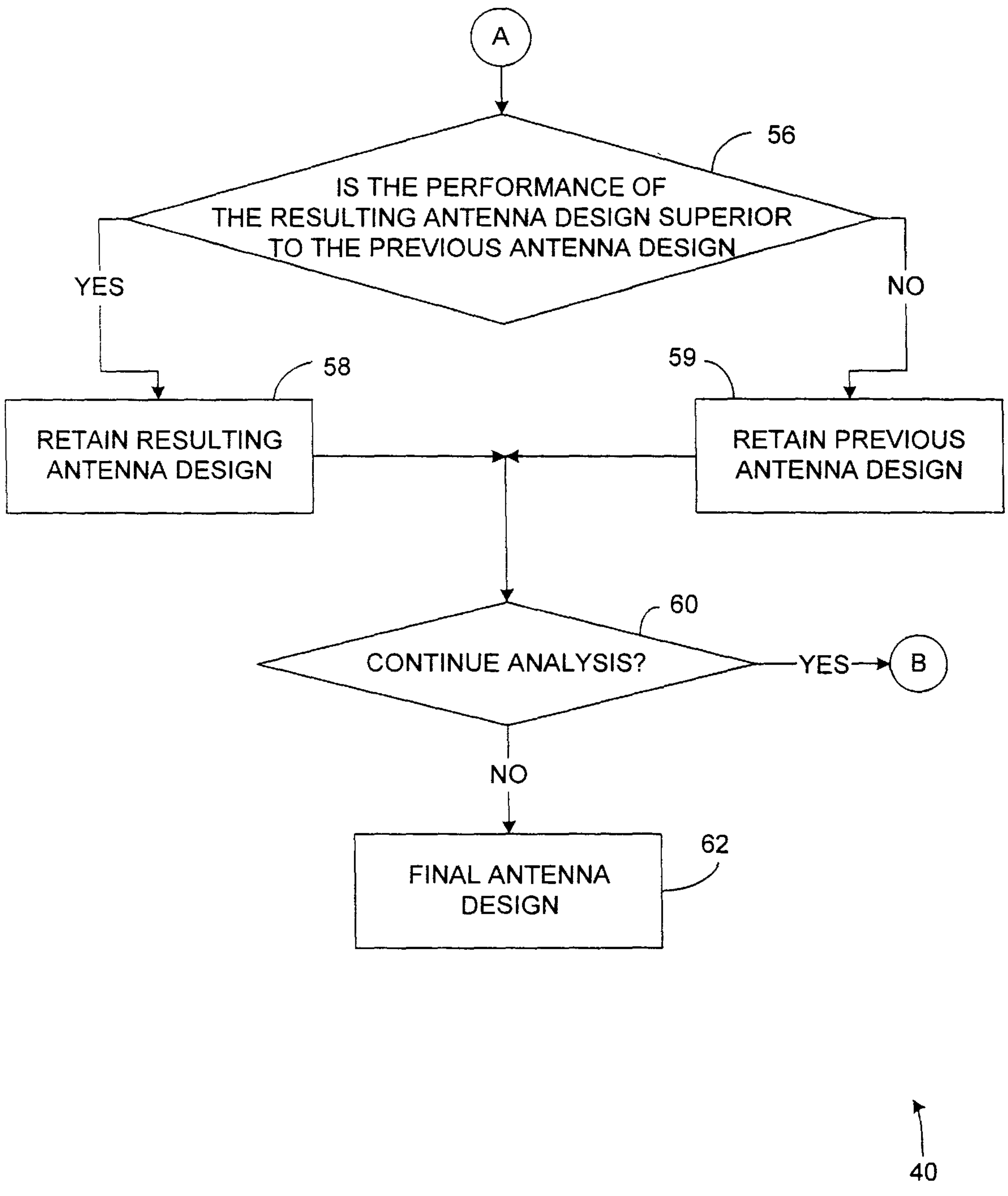

A
IS THE PERFORMANCE OF THE RESULTING ANTENNA DESIGN SUPERIOR TO THE PREVIOUS ANTENNA DESIGN
56
YES
NO
58
59
RETAIN RESULTING ANTENNA DESIGN
RETAIN PREVIOUS ANTENNA DESIGN
60
CONTINUE ANALYSIS?
YES
B
NO
FINAL ANTENNA DESIGN
62
40

FIG. 6

MEASURED AND PREDICTED PERFORMANCE FOR ANTENNA 20

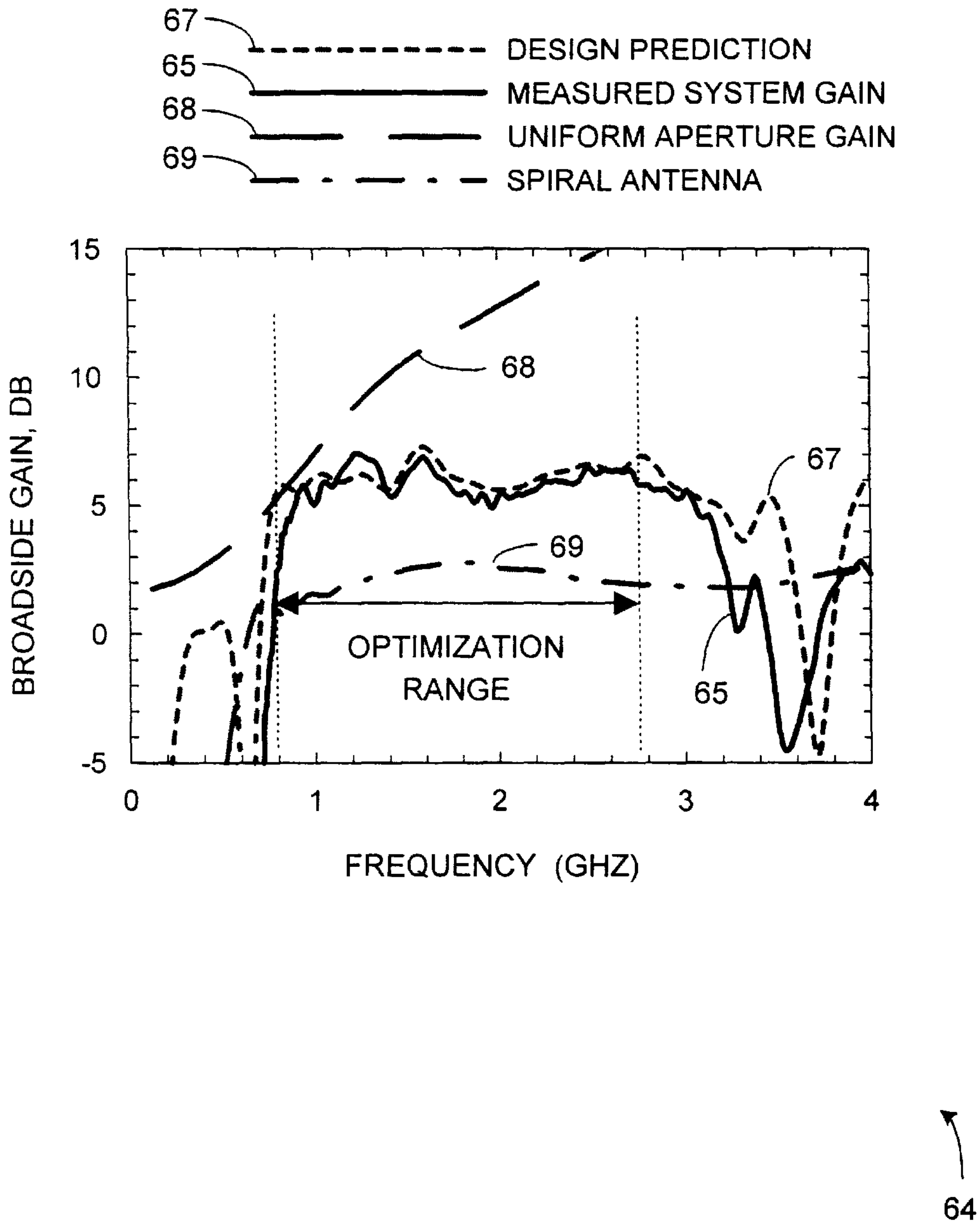
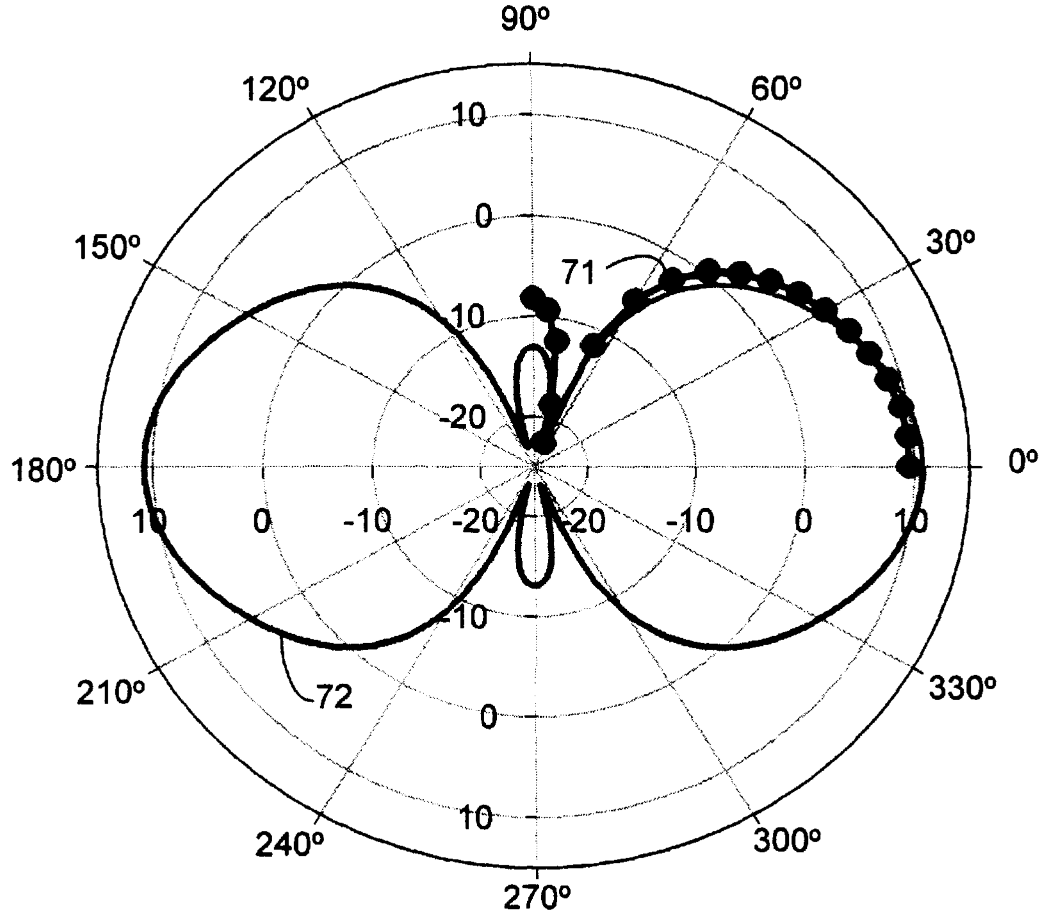


FIG. 7

H-PLANE GRAPH



71 MEASURED RADIATION PATTERN

72 FDTD MODEL

70

FIG. 8

FRAGMENTED APERTURE ANTENNA OPTIMIZED OVER THE 0.24 - 2.04 GHZ FREQUENCY RANGE TO ACHIEVE A SYSTEM GAIN THAT FOLLOWS THE UNIFORM APERTURE LIMIT.

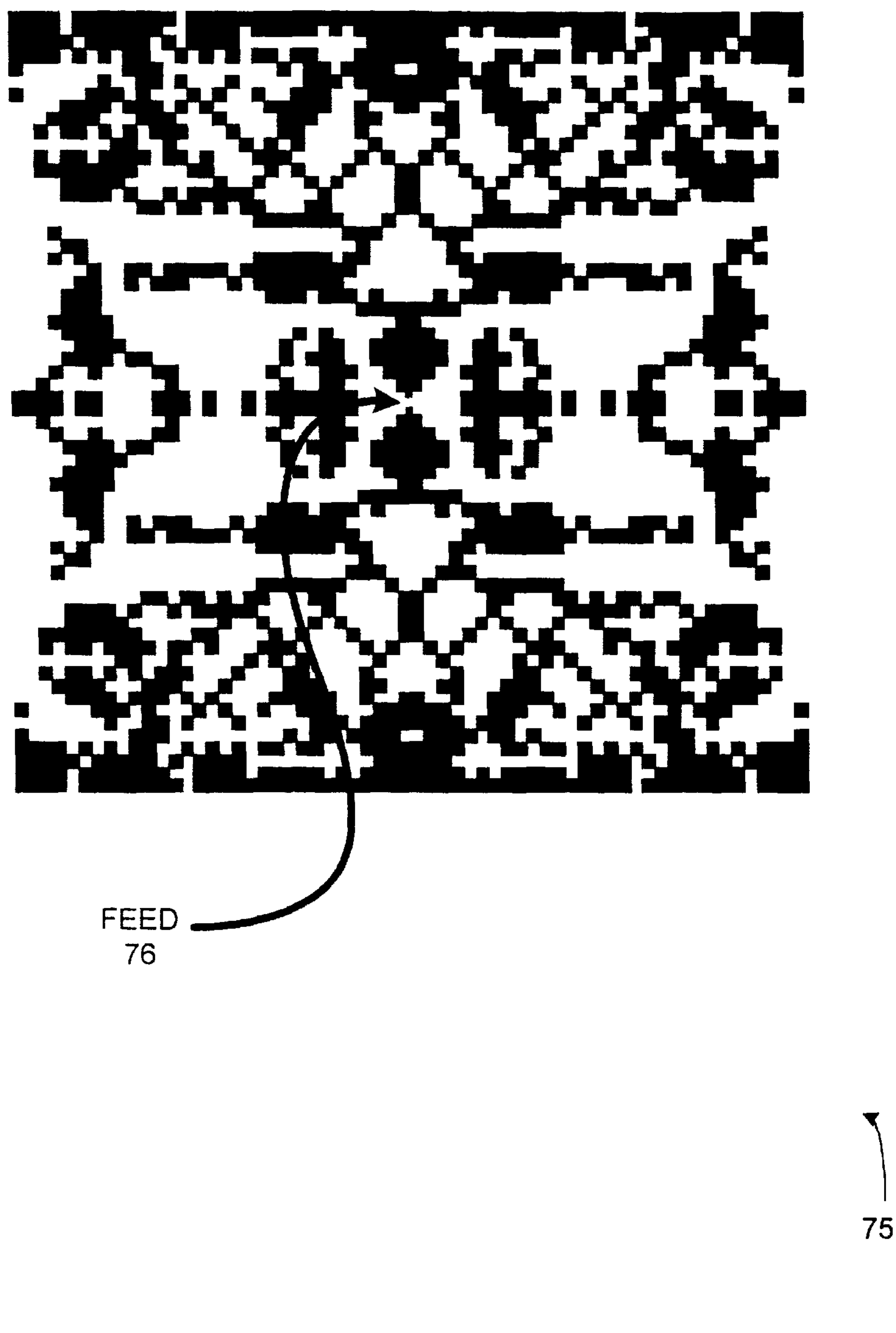


FIG. 9

MEASURED AND PREDICTED PERFORMANCE OF ANTENNA 75

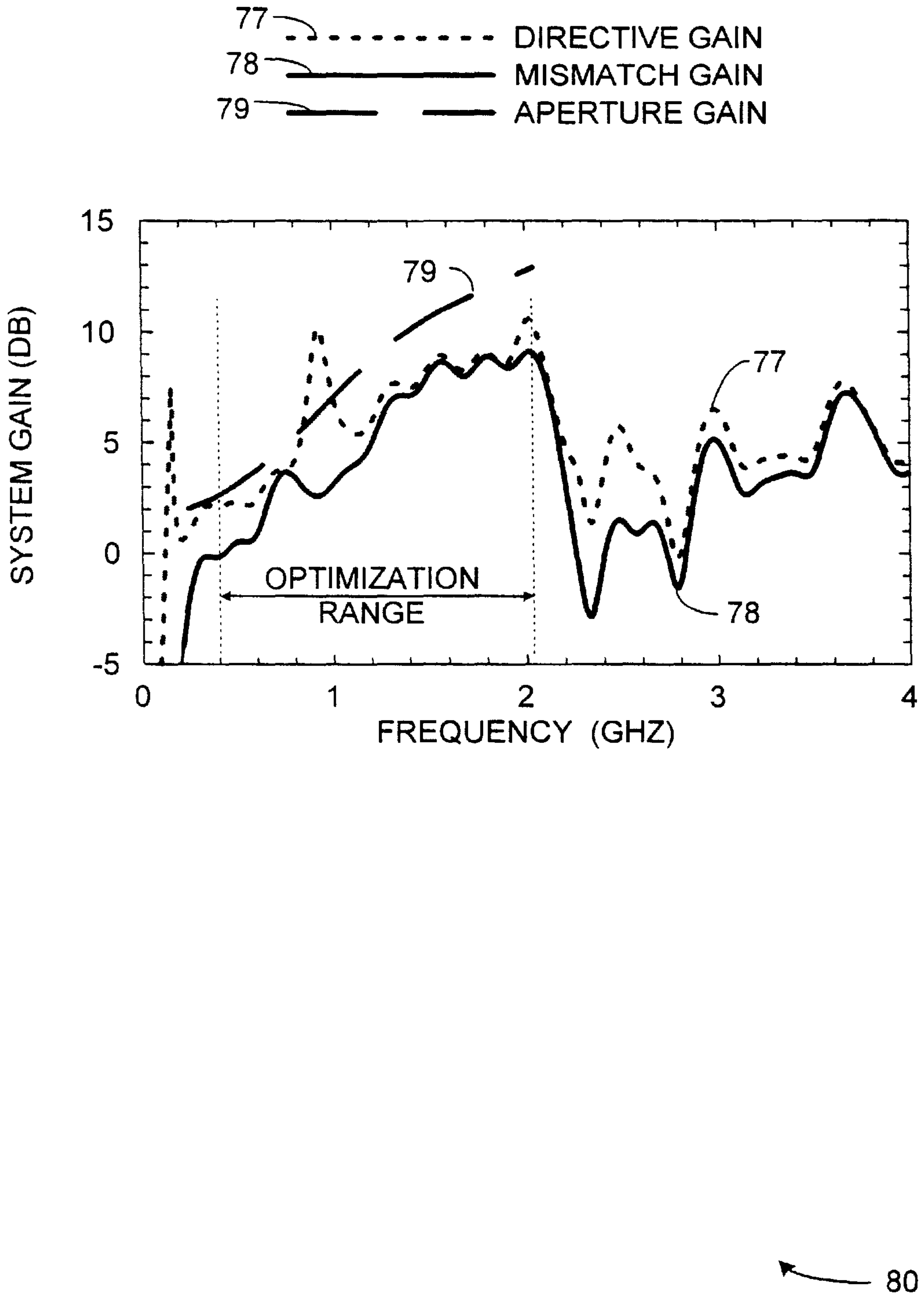


FIG. 10

FRAGMENTED APERTURE ANTENNA OPTIMIZED OVER A 1.4 – 1.8 GHZ
FREQUENCY RANGE

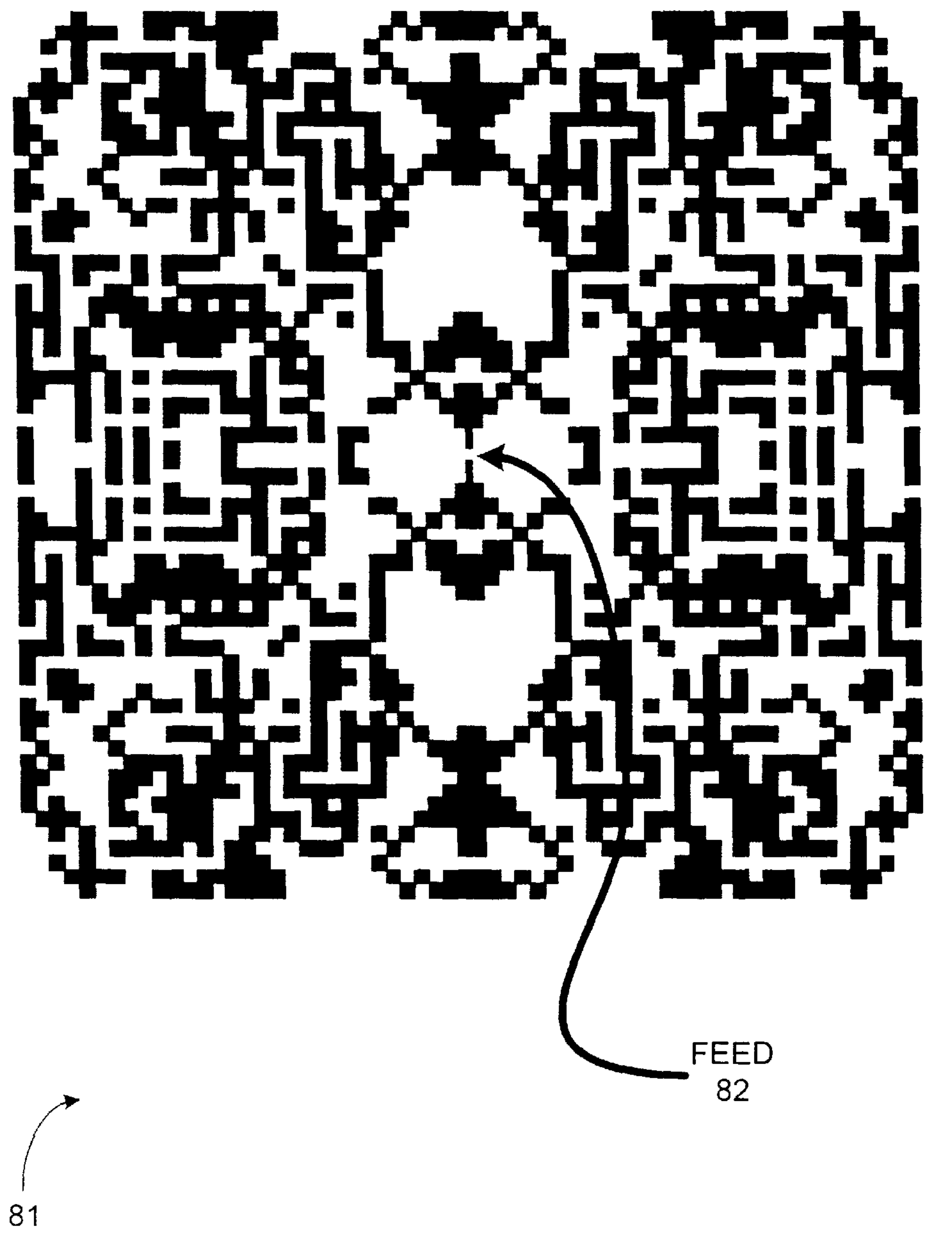


FIG. 11

MEASURED AND PREDICTED PERFORMANCE OF ANTENNA 81

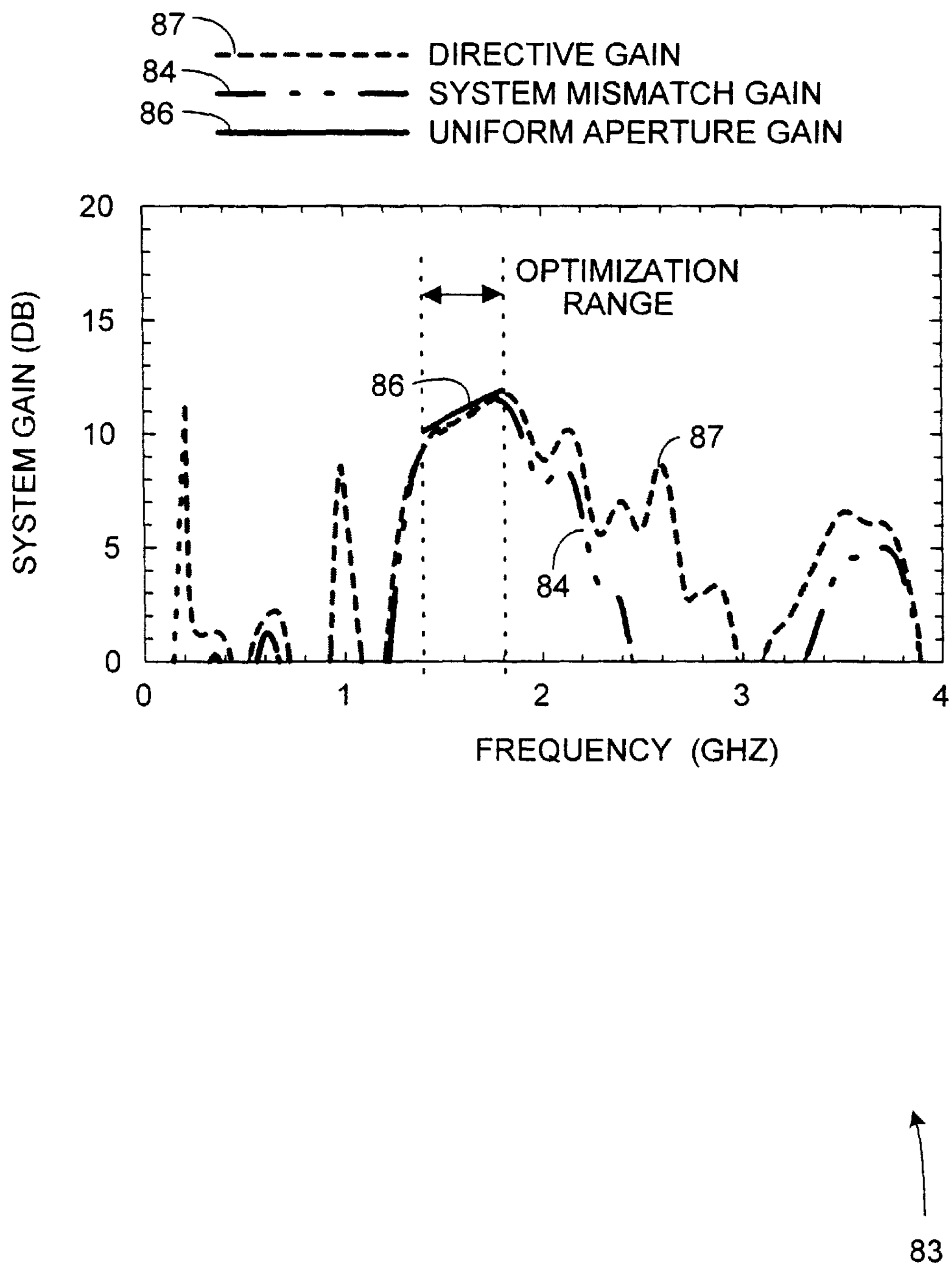
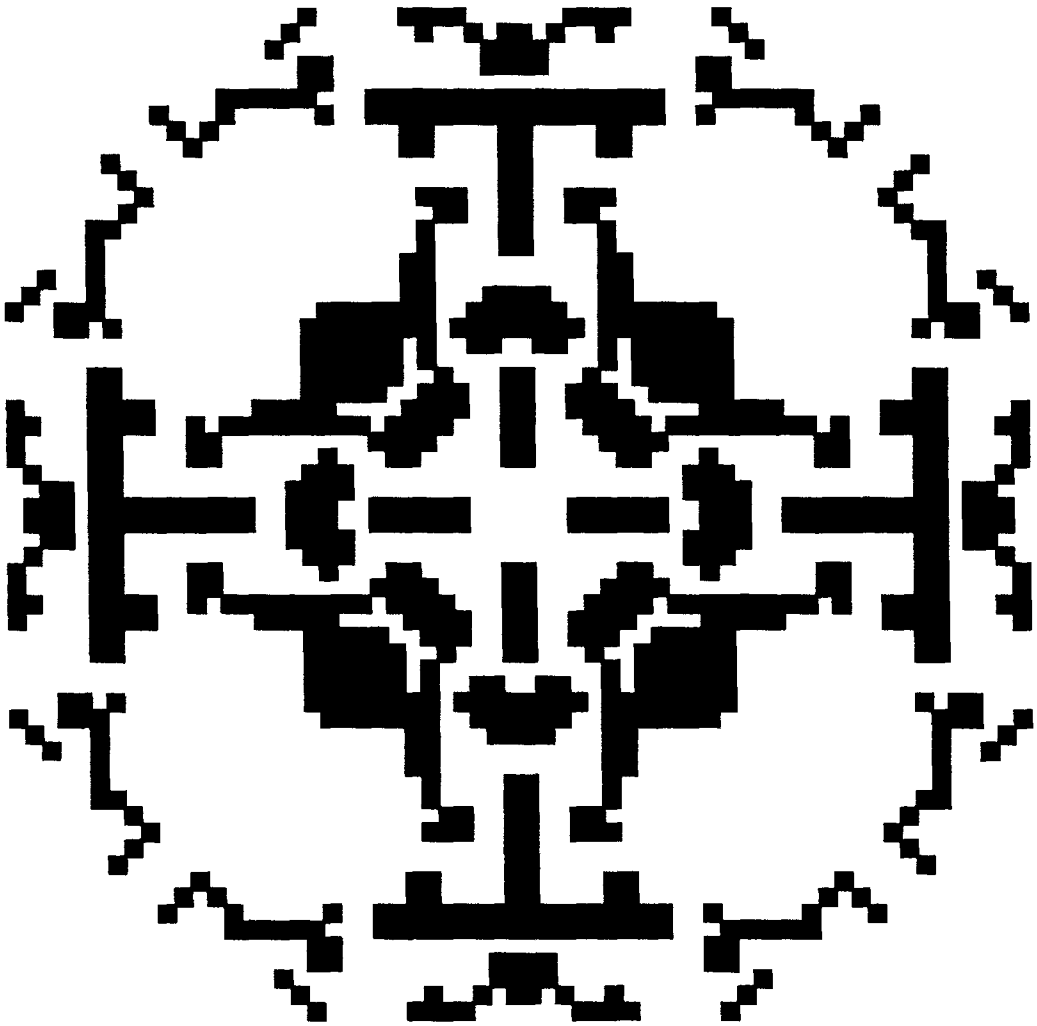


FIG. 12

FRAGMENTED APERTURE ANTENNA OPTIMIZED FOR DUAL POLARIZATION OVER A 1.4 - 1.8 GHZ FREQUENCY RANGE



90

FIG. 13

PREDICTED PERFORMANCE OF THE DUAL POLARIZED ANTENNA 90

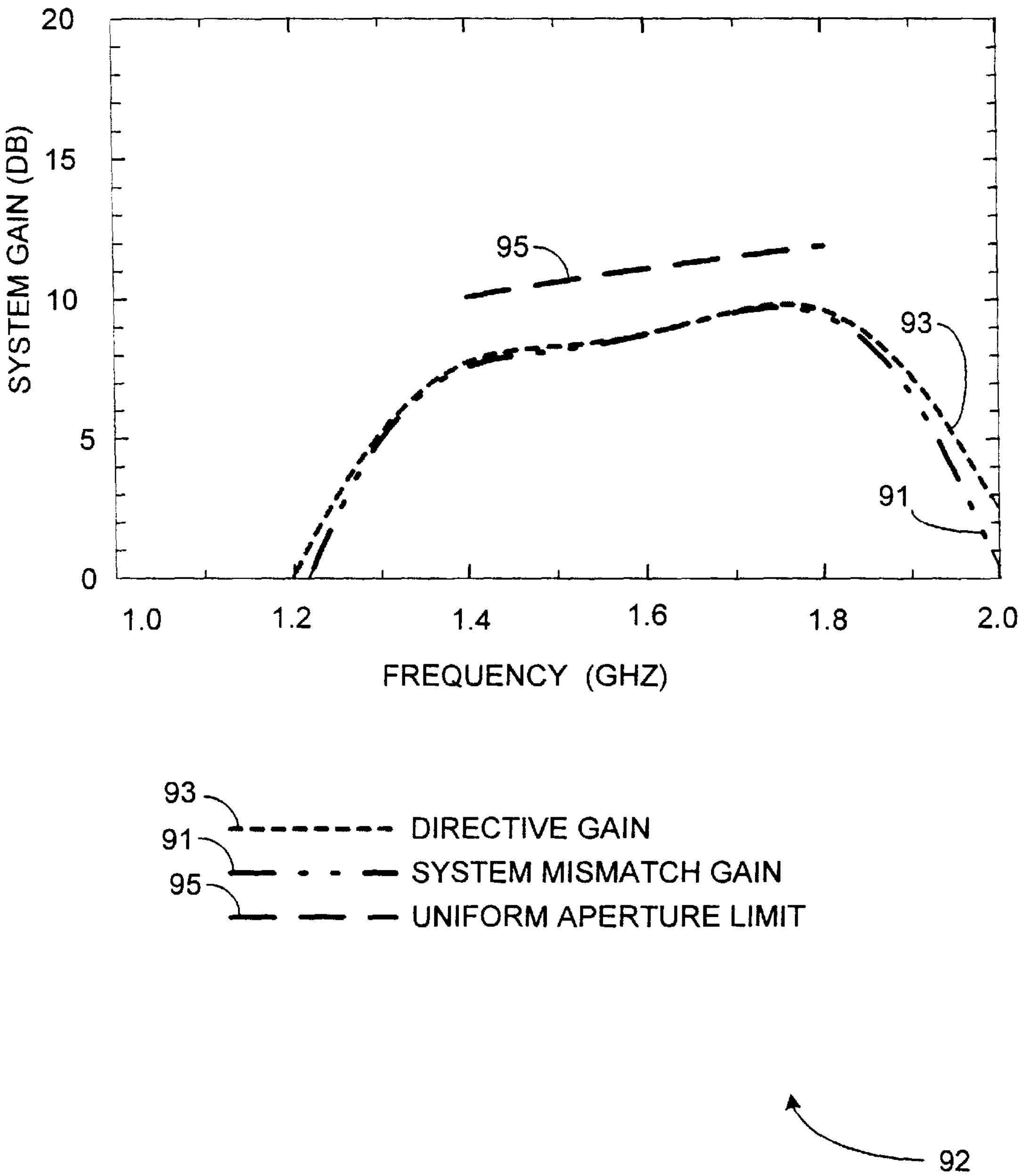


FIG. 14

ANTENNA WITH A GROUND PLANE LAYER

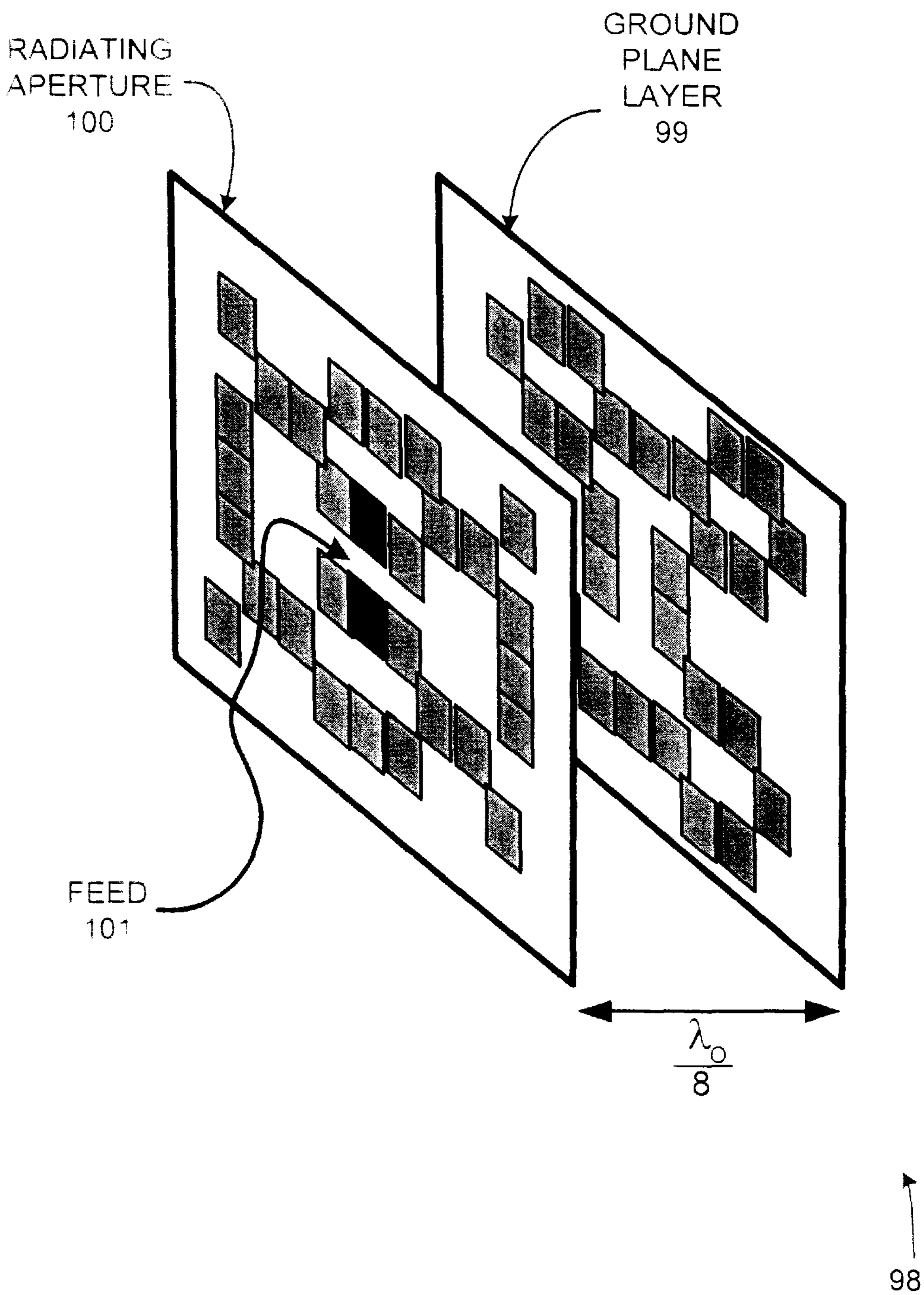


FIG. 15

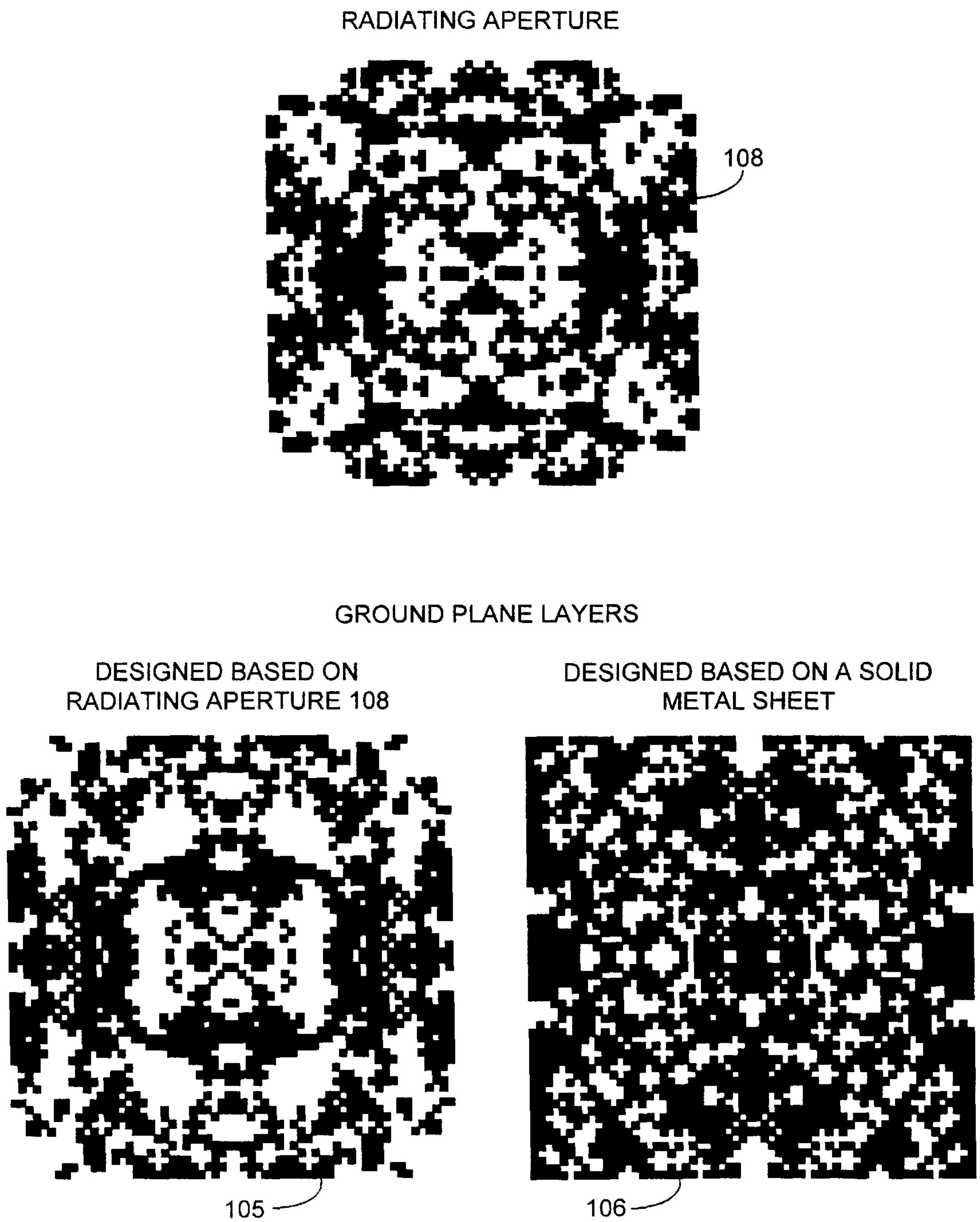

RADIATING APERTURE
108
GROUND PLANE LAYERS
DESIGNED BASED ON
RADIATING APERTURE 108
DESIGNED BASED ON A SOLID
METAL SHEET
105
106

FIG. 16

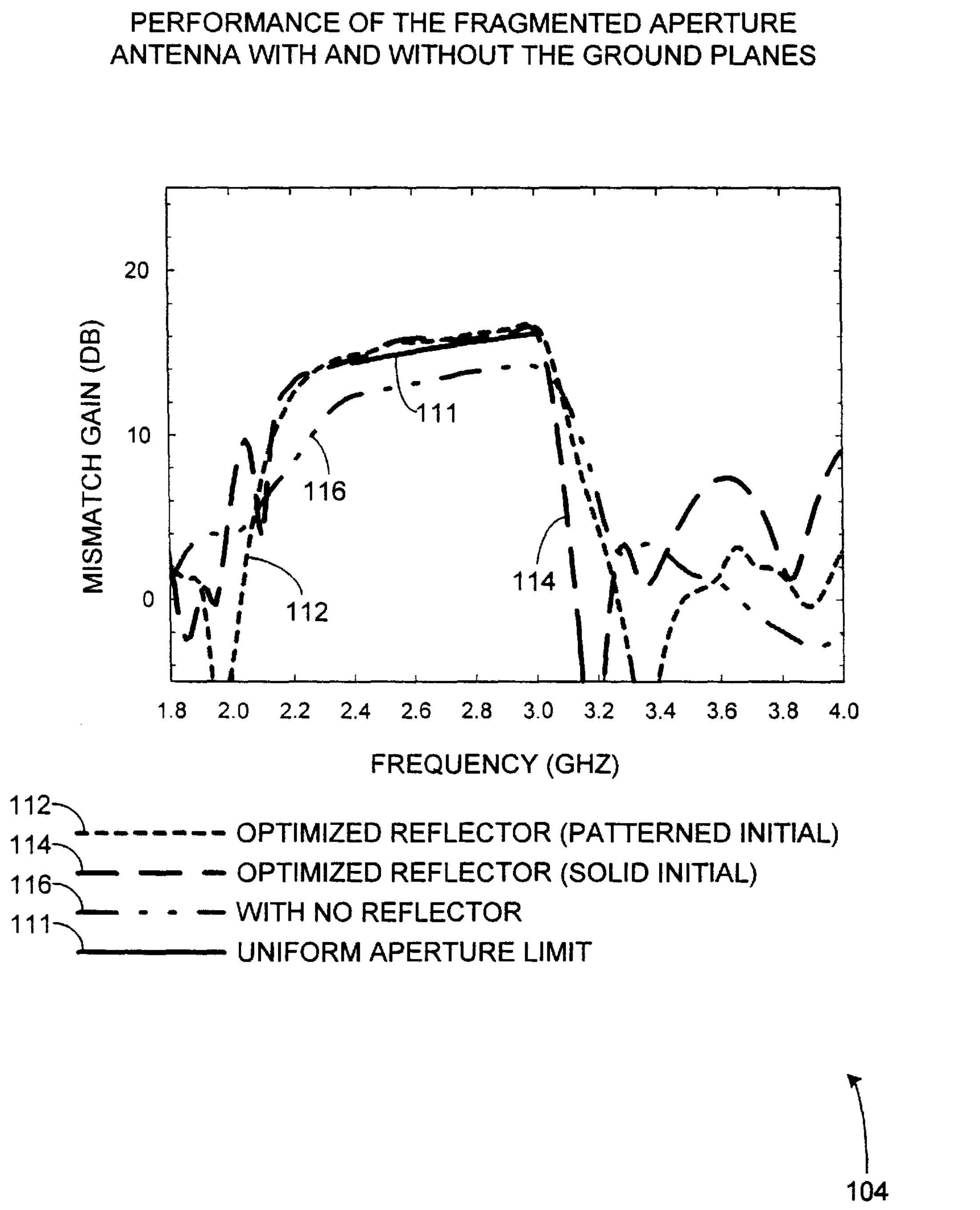
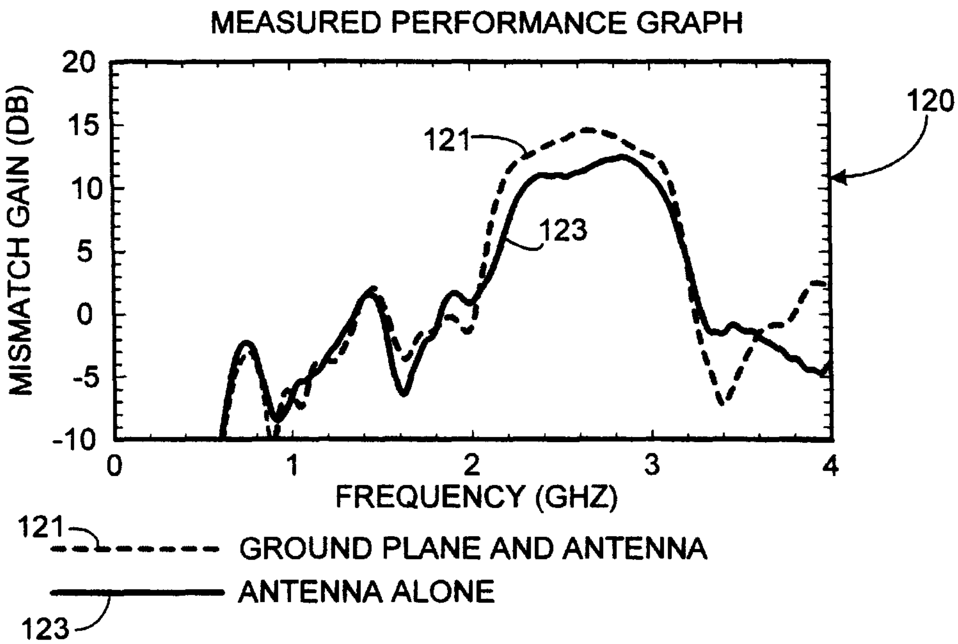

PERFORMANCE OF THE FRAGMENTED APERTURE
ANTENNA WITH AND WITHOUT THE GROUND PLANES
MISMATCH GAIN (DB)
20
10
0
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
FREQUENCY (GHZ)
111
116
112
114
112
OPTIMIZED REFLECTOR (PATTERNED INITIAL)
114
OPTIMIZED REFLECTOR (SOLID INITIAL)
116
WITH NO REFLECTOR
111
UNIFORM APERTURE LIMIT
104

FIG. 17


MEASURED PERFORMANCE GRAPH
MISMATCH GAIN (DB)
20
15
10
5
0
-5
-10
0
1
2
3
4
FREQUENCY (GHZ)
120
121
123
121
GROUND PLANE AND ANTENNA
ANTENNA ALONE
123

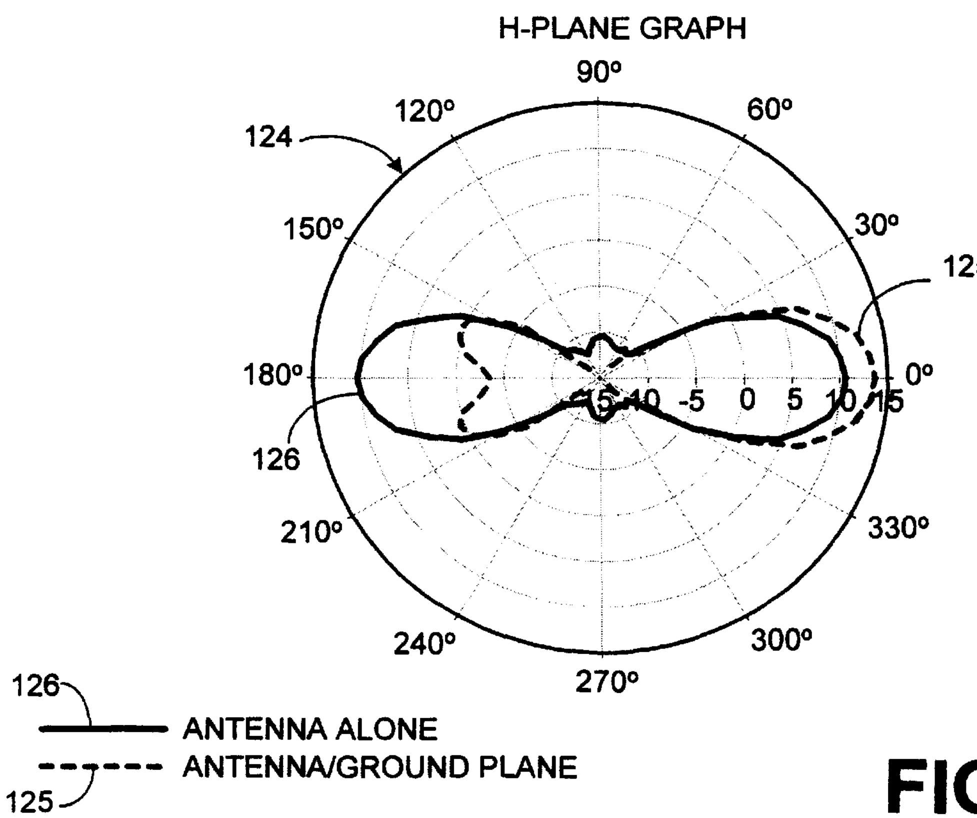

H-PLANE GRAPH
90°
60°
120°
124
150°
30°
125
180°
0°
-15
-10
-5
0
5
10
15
126
210°
330°
240°
300°
270°
126
ANTENNA ALONE
ANTENNA/GROUND PLANE
125

FIG. 18

3 CONNECTED PERCOLATING ARRAY ELEMENT

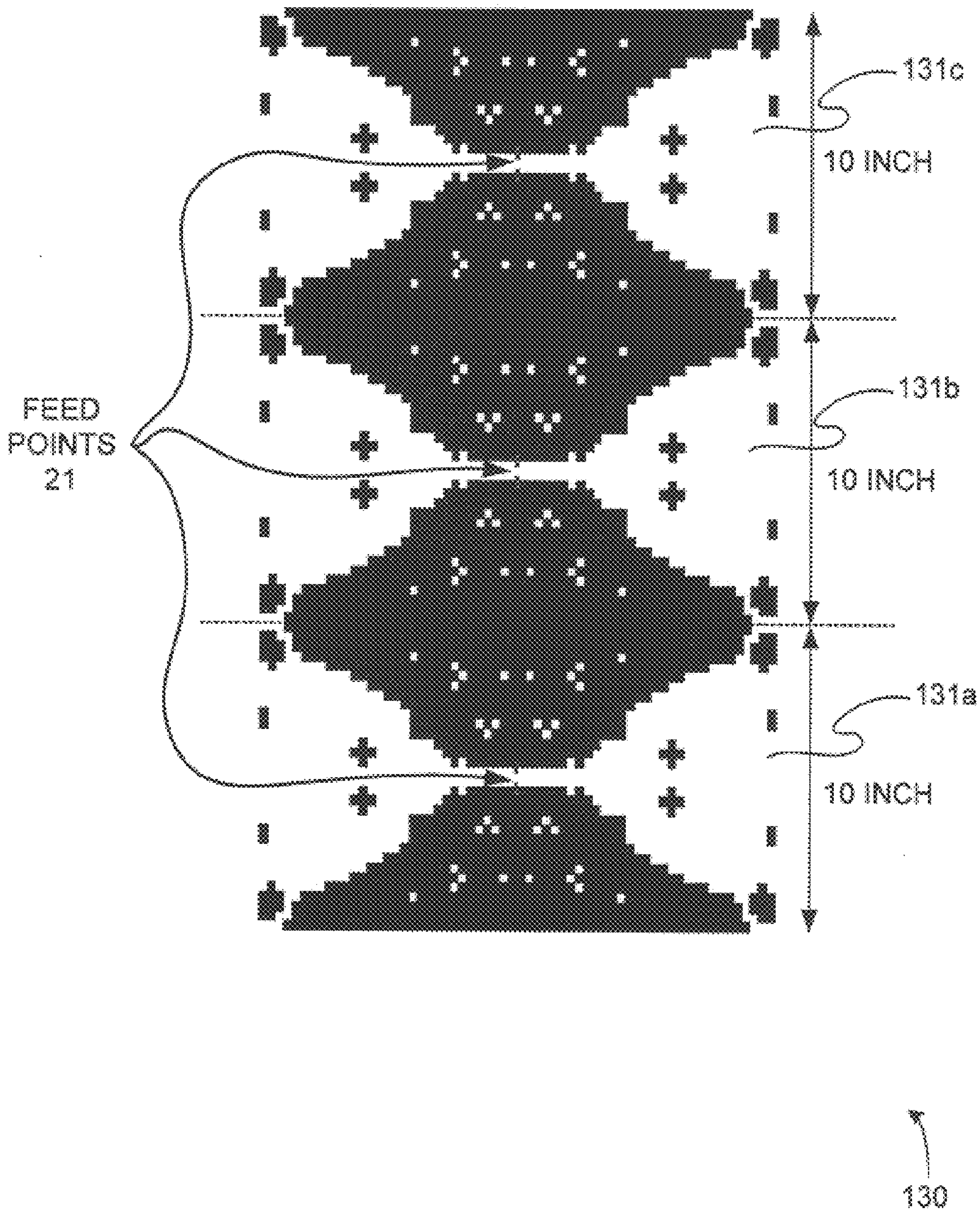


FIG. 19

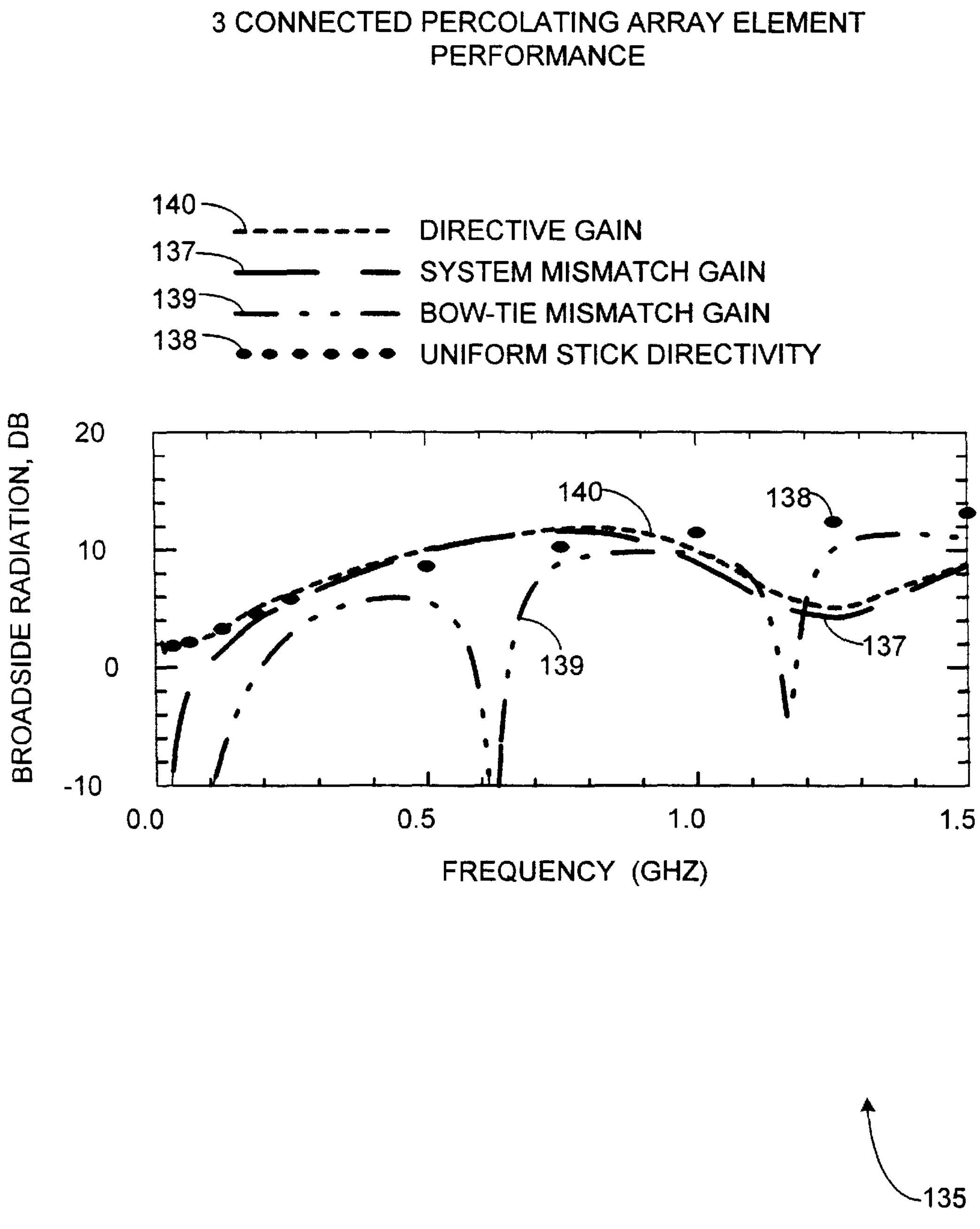

3 CONNECTED PERCOLATING ARRAY ELEMENT PERFORMANCE
140
DIRECTIVE GAIN
137
SYSTEM MISMATCH GAIN
139
BOW-TIE MISMATCH GAIN
138
UNIFORM STICK DIRECTIVITY
BROADSIDE RADIATION, DB
20
10
0
-10
0.0
0.5
1.0
1.5
FREQUENCY (GHZ)
140
138
139
137
135

FIG. 20

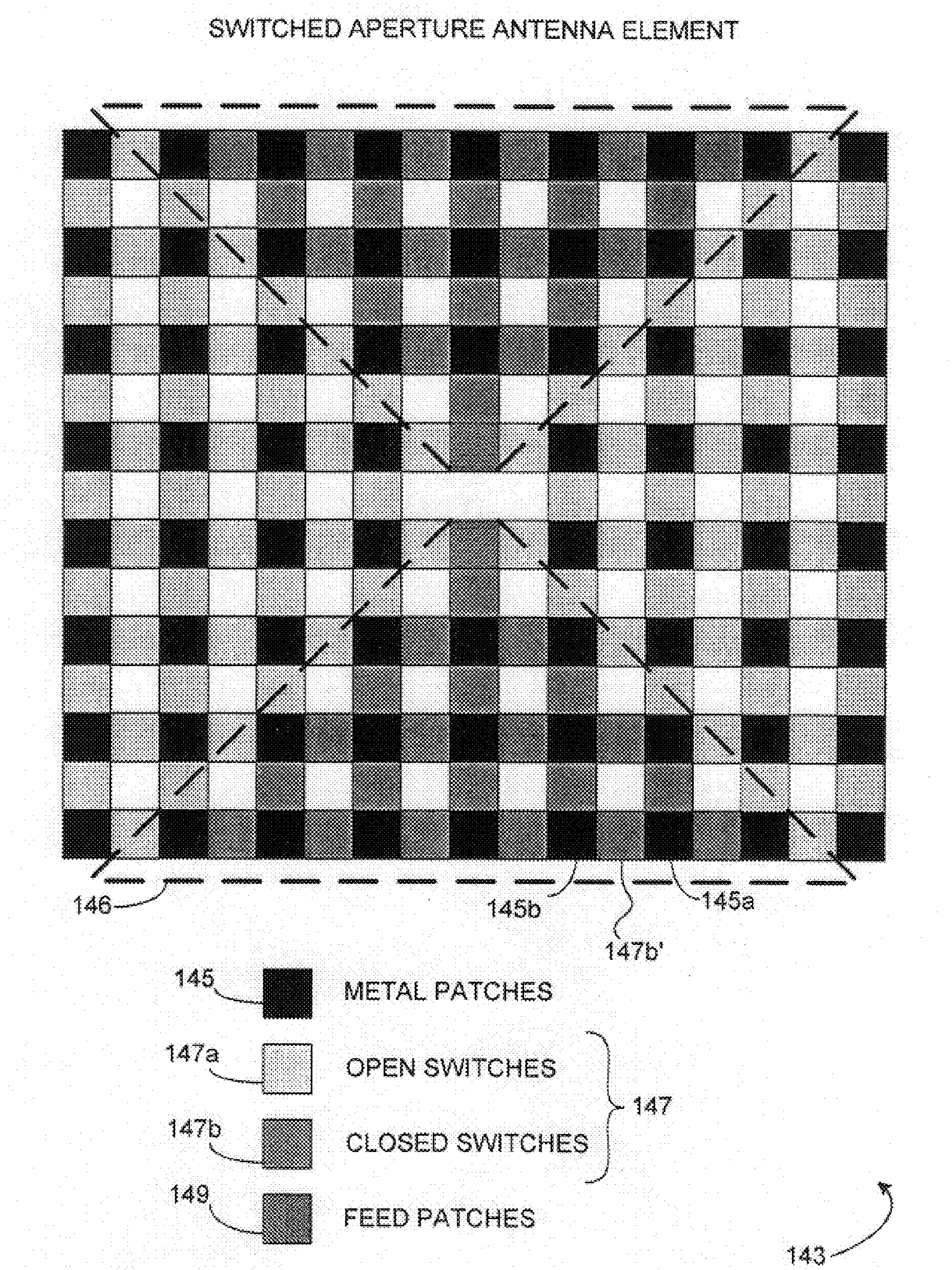

SWITCHED APERTURE ANTENNA ELEMENT
146
145b
145a
147b'
145
METAL PATCHES
147a
OPEN SWITCHES
147b
CLOSED SWITCHES
147
149
FEED PATCHES
143

FIG. 21

1.4 - 1.8 GHZ BROADSIDE SWITCHED APERTURE ANTENNA

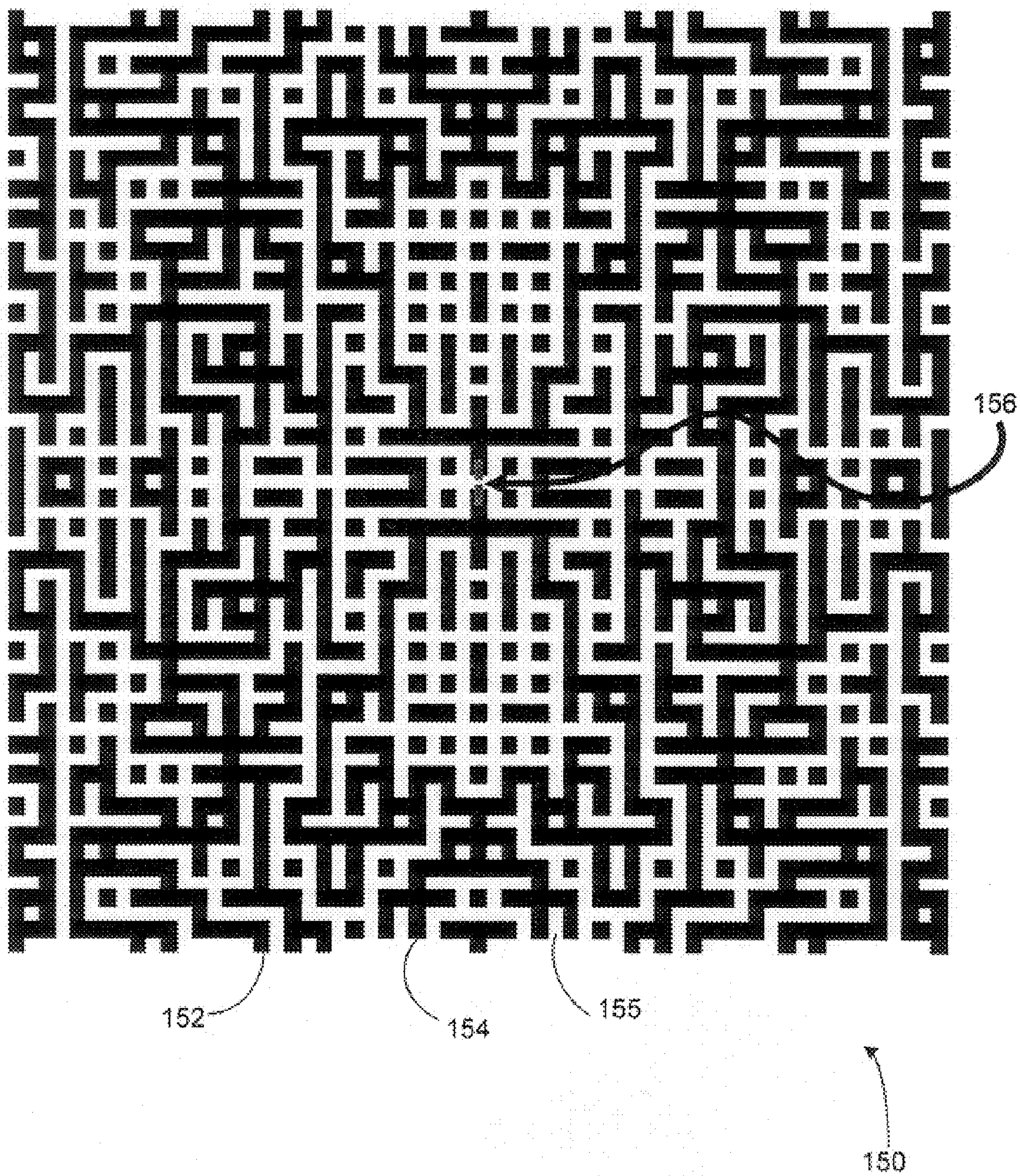


FIG. 22

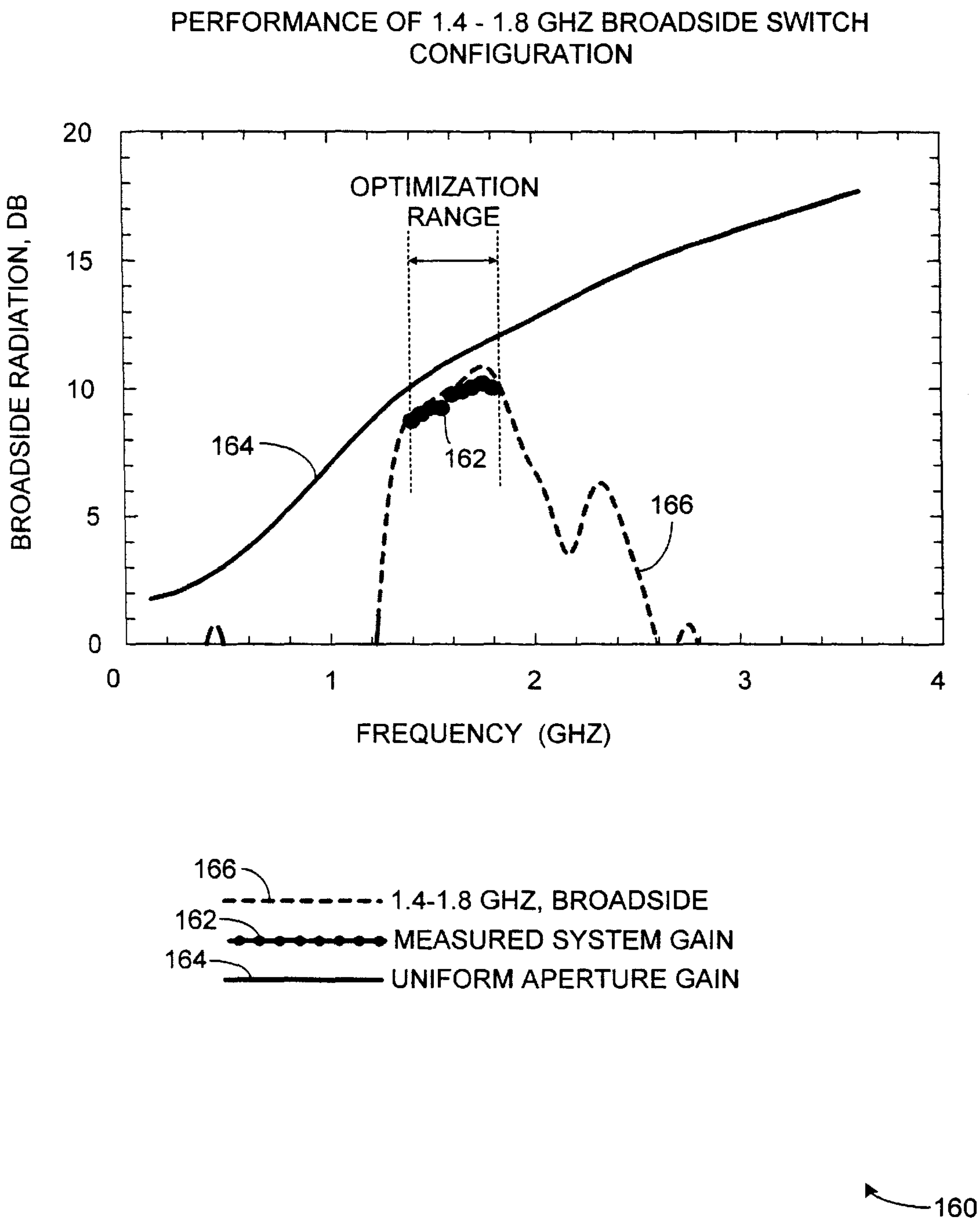

PERFORMANCE OF 1.4 - 1.8 GHZ BROADSIDE SWITCH CONFIGURATION
OPTIMIZATION RANGE
BROADSIDE RADIATION, DB
20
15
10
5
0
0
1
2
3
4
FREQUENCY (GHZ)
164
162
166
166
1.4-1.8 GHZ, BROADSIDE
162
MEASURED SYSTEM GAIN
164
UNIFORM APERTURE GAIN
160

FIG. 23

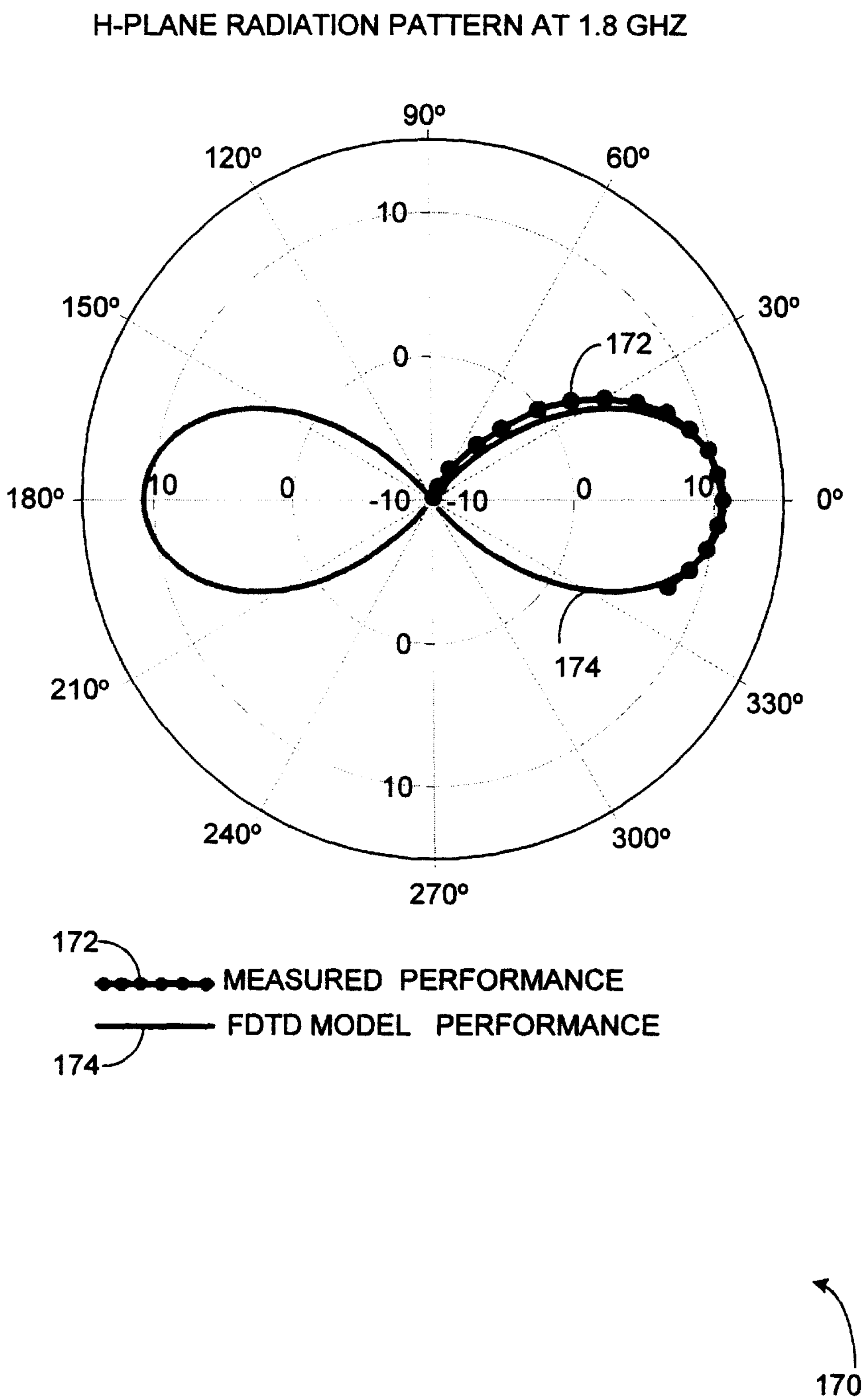

H-PLANE RADIATION PATTERN AT 1.8 GHZ
90°
120°
60°
150°
30°
180°
0°
210°
330°
240°
300°
270°
10
0
-10
172
174
172
MEASURED PERFORMANCE
FDTD MODEL PERFORMANCE
174
170

FIG. 24

1.4 - 1.8 GHZ ANTENNA FOR 30 DEGREE STEERING

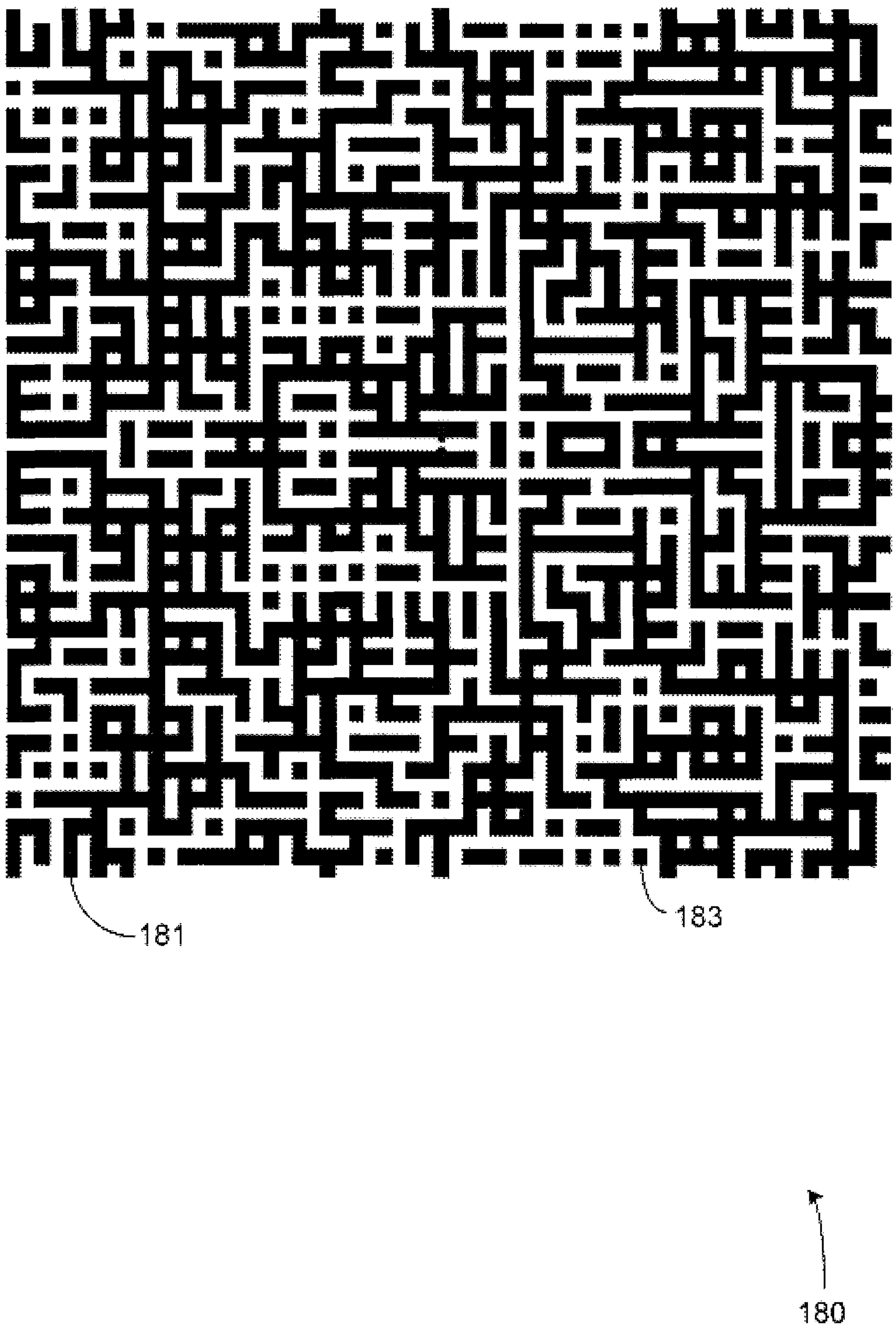


FIG. 25

PERFORMANCE OF 1.4-1.8 GHZ, BROADSIDE SWITCH CONFIGURATION

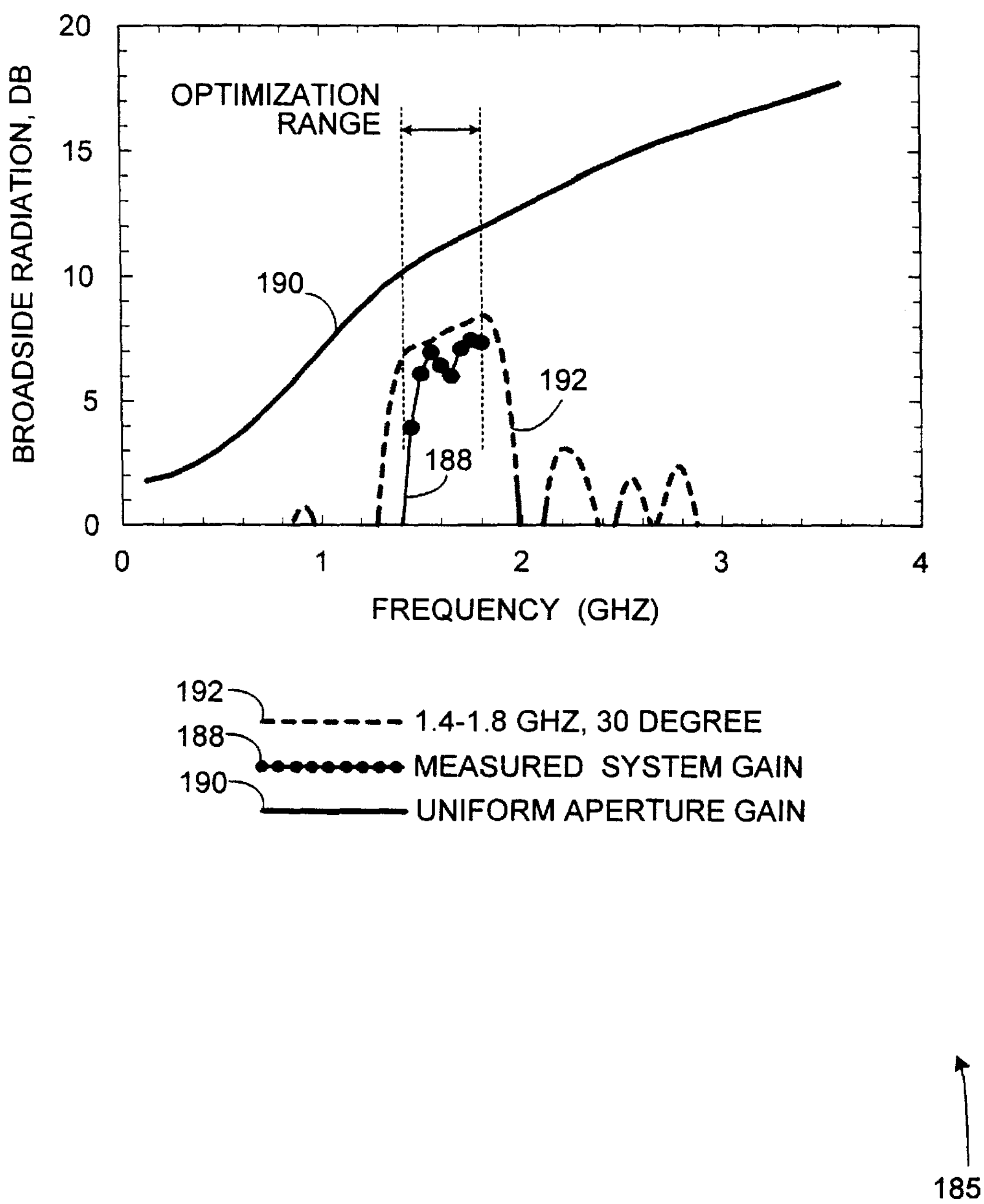


FIG. 26

H-PLANE RADIATION PATTERN AT 1.8 GHZ

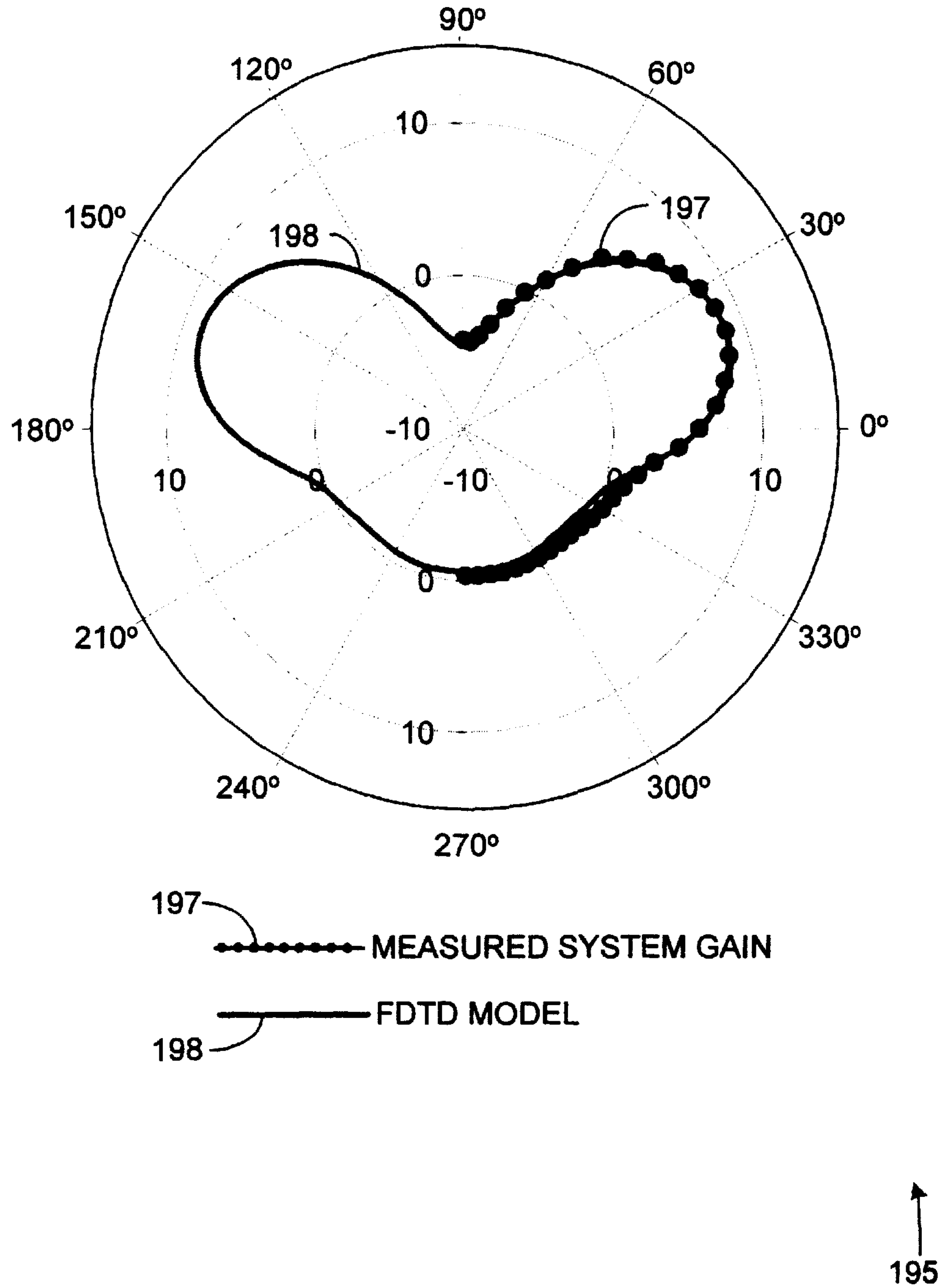


FIG. 27

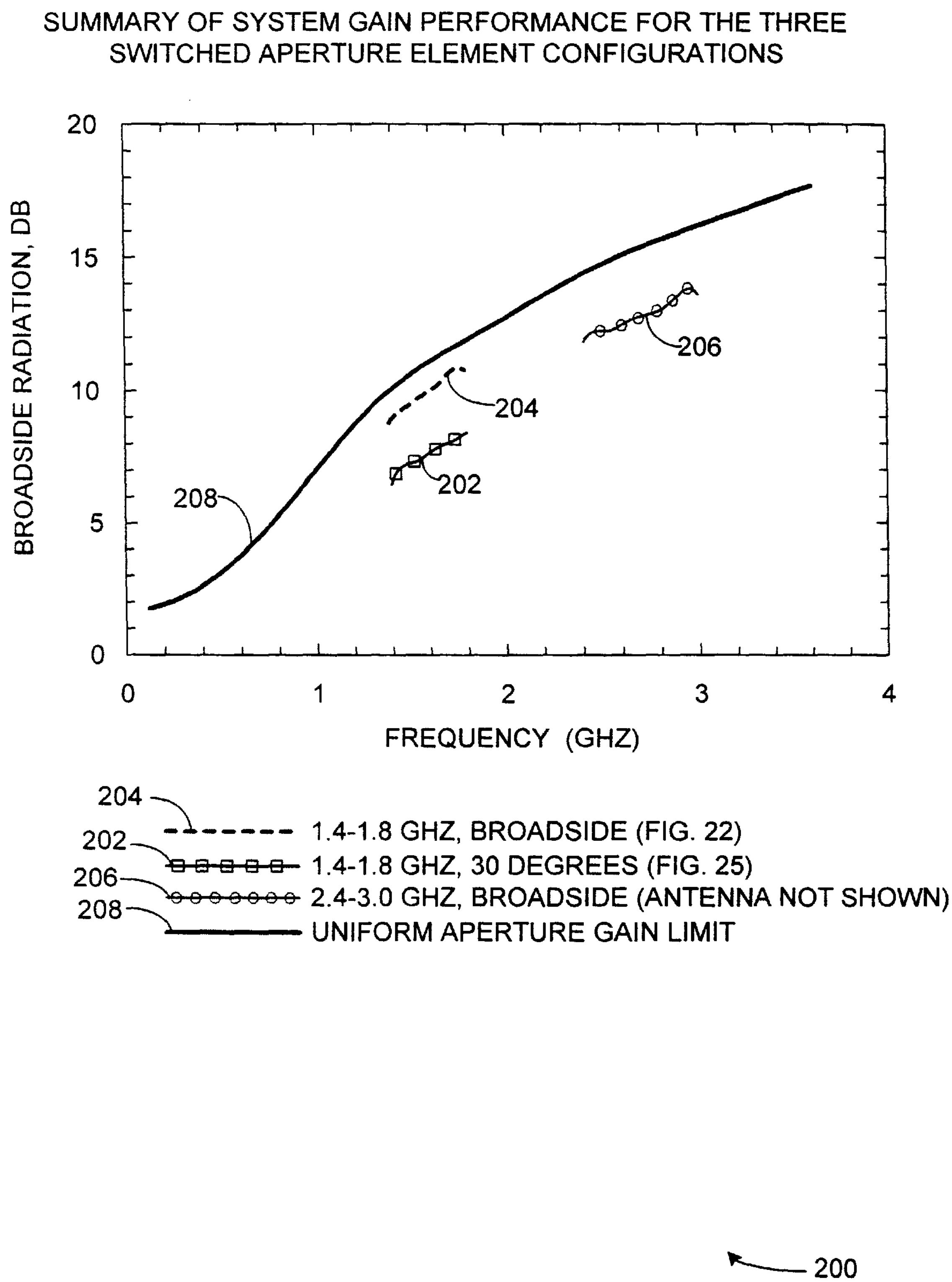

SUMMARY OF SYSTEM GAIN PERFORMANCE FOR THE THREE SWITCHED APERTURE ELEMENT CONFIGURATIONS
BROADSIDE RADIATION, DB
FREQUENCY (GHZ)
0
5
10
15
20
0
1
2
3
4
208
204
202
206
204
1.4-1.8 GHZ, BROADSIDE (FIG. 22)
202
1.4-1.8 GHZ, 30 DEGREES (FIG. 25)
206
2.4-3.0 GHZ, BROADSIDE (ANTENNA NOT SHOWN)
208
UNIFORM APERTURE GAIN LIMIT
200

FIG. 28

SCHEMATIC REPRESENTATION OF A CONNECTED ARRAY OF RECONFIGURABLE APERTURE ELEMENTS

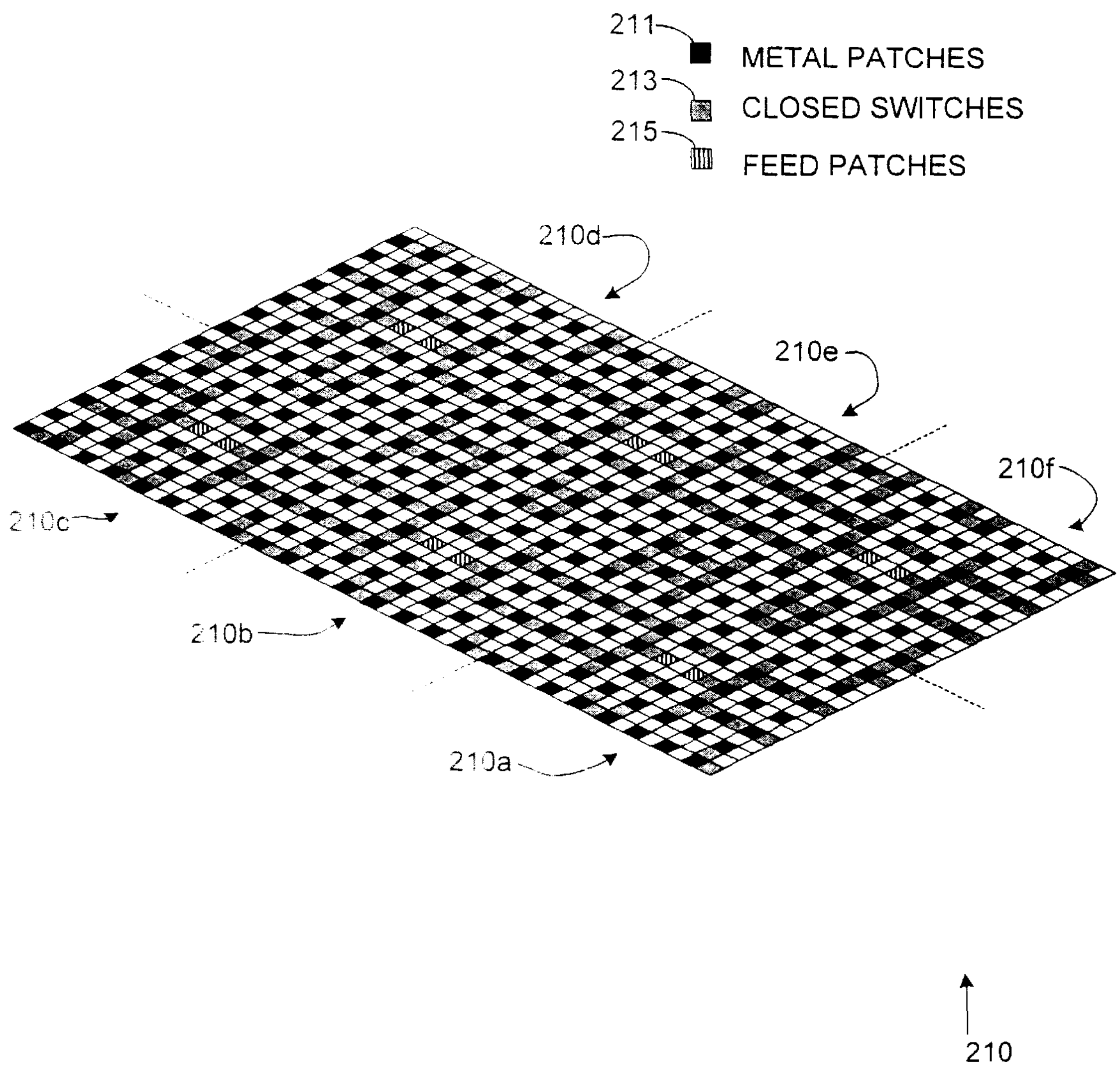


FIG. 29

FRAGMENTED APERTURE ANTENNA CREATED IN SCREEN PRINTING TECHNIQUE

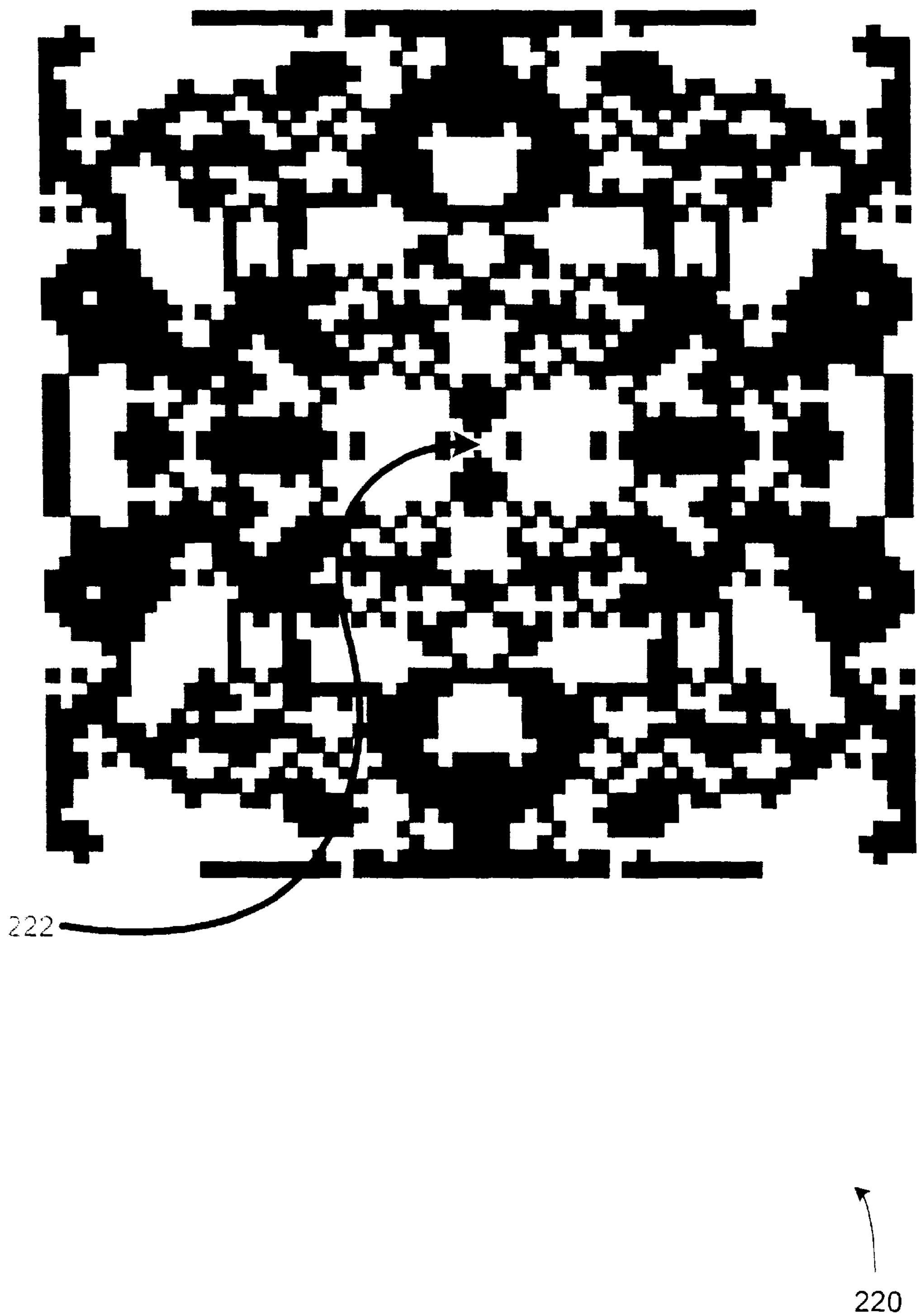


FIG. 30

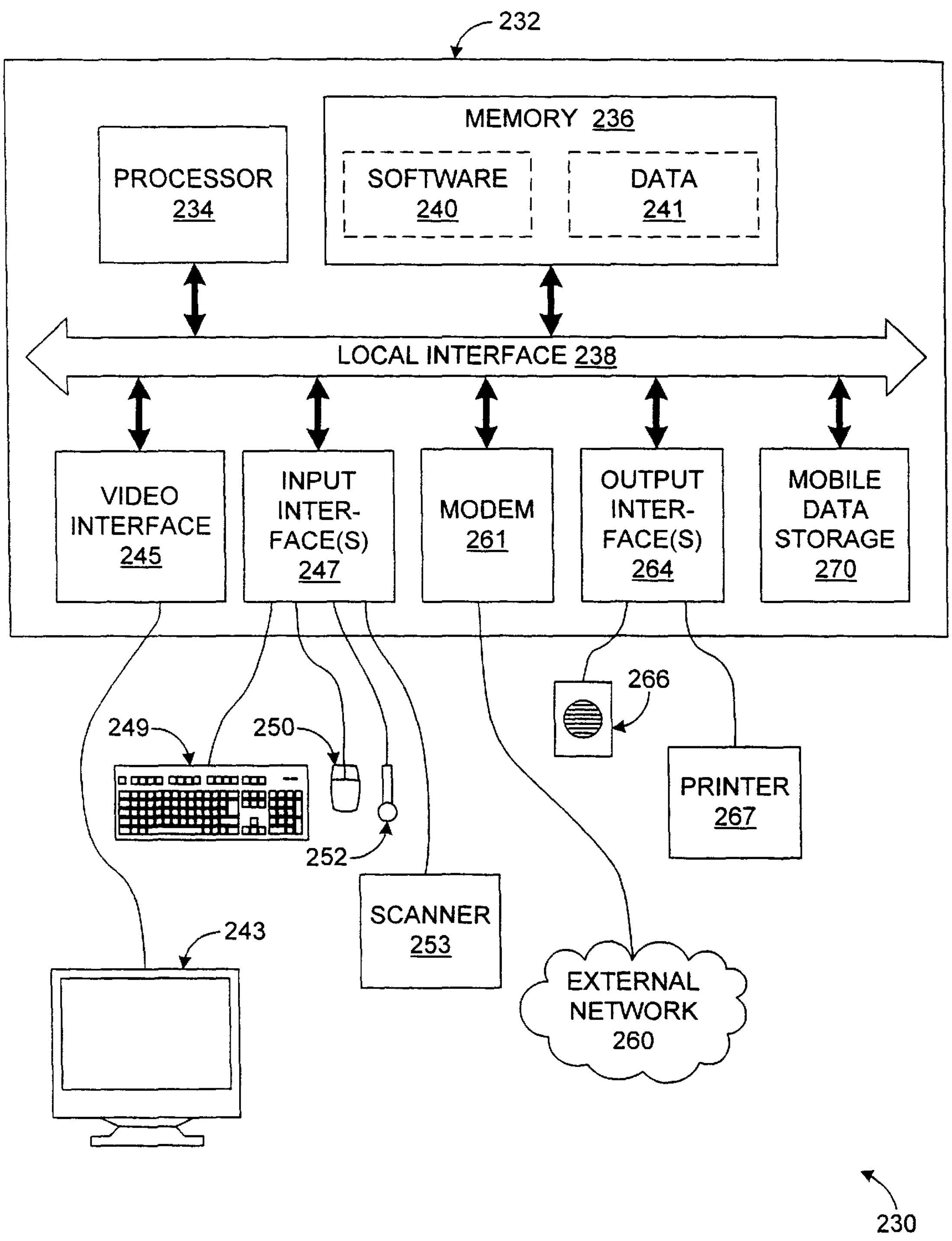

232
MEMORY 236
PROCESSOR 234
SOFTWARE 240
DATA 241
LOCAL INTERFACE 238
VIDEO INTERFACE 245
INPUT INTER-FACE(S) 247
MODEM 261
OUTPUT INTER-FACE(S) 264
MOBILE DATA STORAGE 270
266
249
250
252
PRINTER 267
SCANNER 253
243
EXTERNAL NETWORK 260
230

FIG. 31

FRAGMENTED APERTURE ANTENNAS AND BROADBAND ANTENNA GROUND PLANES

CLAIM OF PRIORITY

This application claims priority to copending U.S. Provisional Application entitled, "Fragmented Aperture Antennas and Broadband Antenna Ground Planes," having Ser. No. 60/136,721, filed May 28, 1999, which is entirely incorporated herein by reference.

GOVERNMENT LICENSE RIGHTS

The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of contract No. XXXXXX-97-C-1229 awarded by the Department of Defense of the United States of America. The prefix XXXXXX is classified confidential.

FIELD OF THE INVENTION

This invention relates in general to the field of broadband antennas, and more particularly, to fragmented aperture antennas with tailored electromagnetic performances.

BACKGROUND OF THE INVENTION

An antenna is a device that can both transmit and receive electromagnetic waves of energy. Designing an antenna can be a complicated task because of the inherent properties of electromagnetics. Presently, antenna engineers physically scale or modify conventional antennas to best meet a particular application. However, in many instances, this procedure is suboptimal because a suitable conventional antenna may not exist or is not similar enough to meet a particular need. Antennas with broadband frequency coverage are desirable so the antenna can operate in a greater number of applications, but many conventional antennas with broadband coverage also include inadequacies that render them ultimately unacceptable.

For example, a multi-turn spiral antenna is a broadband antenna. However, the gain of the spiral antenna is essentially flat with frequency. The optimal use of the aperture area would yield a gain that increases with frequency, so the spiral antenna is suboptimal from because of its increases in gain over frequency.

Another example of a broadband antenna is the bow-tie antenna. A bow-tie antenna will radiate over a wide range of frequencies. Because the direction of radiation for the bow-tie antenna changes over the range of frequency, this feature renders the bowtie as suboptimal.

Thus, there is a need for an antenna that can overcome these limitations, deficiencies and inadequacies that is heretofore unaddressed.

SUMMARY OF THE INVENTION

Briefly described, the preferred embodiment of the present invention provides a new family of antennas—fragmented aperture antennas. The antenna includes a planar layer having a plurality of conductive and substantially non-conductive areas. Each area has a periphery that extends along a grid of first and second sets of parallel lines so that each area comprises one or more contiguous elements defined by the parallel lines. The locations of the conducting materials in the fragmented aperture antenna are determined by a multi-stage optimization procedure that tailors the

performance of the antenna to a particular application. The resulting configuration and arrangement of conductive and substantially non-conductive areas enable communication of electromagnetic energy wirelessly in a specific direction to the planar layer when an electrical connection is made to at least one of the conductive areas.

The present invention can also be viewed as providing one or more methods. As an example, one such method is for making an antenna. The method includes a step of defining a planar grid defined by first and second sets of parallel lines so that the grid comprises a plurality of elements defined by the lines. The method additionally includes determining a first plurality of said elements that should be substantially conductive and a second plurality of said elements that should be substantially nonconductive so that a hypothetical antenna formed from said planar grid elements exhibits a desired frequency spectrum.

In an alternative embodiment, a broadband ground plane is created by using a similar optimization strategy as described above. The fragmented ground plane is a second patterned sheet placed behind the radiating layer to reflect the energy in the forward direction of the antenna. The fragmented ground plane is a patterned layer similar to the radiating antenna aperture. A feed is applied to the radiating aperture, and the ground plane layer is placed in parallel to the radiating aperture at a predetermined distance.

The single fragmented aperture antenna as described above may also be placed in an array of multiple antenna elements. In an alternative embodiment, the fragmented aperture antennas configured in the array environment are allowed, through the optimization process, to physically touch neighboring antenna elements, thereby creating a connected array. To create the connected antenna array, a suitable antenna element is selected and then the spacing and size are chosen such that no grating lobes exist and that the required array gain is met. In the connected array, the individual antenna array elements may physically touch, so the embedded array behavior does not resemble the isolated antenna behavior. By allowing the individual antenna array elements to touch, the low frequency limit of operation is not set by the size of the isolated elements, but rather, it is set by the size of the array antenna.

Another embodiment of the invention realizes a reconfigurable aperture and achieves multiple fragmented aperture designs from a single aperture. The reconfigurable aperture is comprised of conducting elements and configurable switches that may be opened or closed to create a fragmented antenna. The switches may be configured to steer the emitted energy at some predetermined angle from broadside.

In yet another alternative embodiment, the switched aperture antenna may be constructed in a connected array such that a large configurable aperture is comprised of an array of identically smaller, reconfigurable elements. The switched fragmented aperture array structure is a connected array similar to the connected non-switched arrays as discussed above. Metal patches are connected by closed switches to form the antenna array. A separate feed patch feeds each antenna element of the array. In the switched fragmented aperture array, the antenna elements in the array may physically touch; hence, the embedded array behavior does not resemble the isolated antenna behavior. Different configurations of a configurable array can operate broadband for a particular set of beam widths and steering angles, and the configuration of each array element can be changed from different beam widths and steering angles.

Many antennas, methods, features, and advantages of the present invention will become apparent to one with skill in the art upon examination of the following drawings and detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. In the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** is a diagram of an antenna having pattern structures of conducting and substantially non-conducting elements utilizing the notion of percolation physics.

FIG. **2** is a diagram depicting the phase of the plane wave transmission coefficient for the antenna of FIG. **1** compared to that of a homogenous dielectric sheet.

FIG. **3** is a diagram of a fragmented aperture antenna optimized to operate from 800 MHz to 2.5 GHz with flat 6 dB system gain.

FIG. **4** is a diagram of a set of trapezoidal conducting strips arranged in fixed locations to provide a coarse description of the antenna ultimately developed as shown in FIG. **3**.

FIGS. **5** and **6** are flowcharts of the two-step optimization process implemented by the computer of FIG. **5** to create, for example, the antenna shown in FIG. **3**.

FIG. **7** is a diagram of the predicted and measured performance of the antenna radiating structure in FIG. **3**.

FIG. **8** is a graph of the measured H-plane radiation pattern of the antenna in FIG. **3** as compared to the design prediction.

FIG. **9** is a diagram of a fragmented aperture antenna over a 0.4–2.04 GHz optimized frequency range to achieve a system gain that follows the uniform aperture limit and was designed by the two-step optimization process shown in FIGS. **5** and **6**.

FIG. **10** is a graph of the predicted performance of the antenna in FIG. **9** showing the directive gain, system mismatch gain and uniform aperture gain.

FIG. **11** is a diagram of a fragmented aperture antenna designed by the two-step optimization process shown in FIGS. **5** and **6** and optimized over a 1.4–1.8 GHz frequency range to achieve a system gain that follows the uniform aperture limit.

FIG. **12** is a graph of the performance for the antenna displayed in FIG. **11**.

FIG. **13** is a fragmented aperture antenna designed by the two-step optimization process shown in FIGS. **5** and **6** and optimized for dual polarization over a 1.4–1.8 GHz frequency range.

FIG. **14** is a graph of the predicted performance of the antenna displayed in FIG. **13**.

FIG. **15** is a diagram of an antenna designed by the two-step optimization process shown in FIGS. **5** and **6** with a fragmented ground plane.

FIG. **16** is a diagram of two separate ground plane layers designed for the same radiating aperture.

FIG. **17** is a graph of the performance of the fragmented aperture with the ground plane layers shown in FIG. **16** as compared to the uniform aperture limit.

FIG. **18** is a graph of the measured performance of the fragmented aperture antenna in FIG. **16** with a ground plane to show performance improvement.

FIG. **19** is a diagram of three fragmented aperture antennas arranged in a connected antenna array similar to the antenna shown in FIG. **3**.

FIG. **20** is a graph of the performance of the antenna array shown in FIG. **19**.

FIG. **21** is a diagram of a switched aperture antenna element arranged to form a fragmented aperture antenna similar to the antenna shown in FIG. **3**.

FIG. **22** is a switched aperture antenna similar to the antenna shown in FIG. **21** with several switches closed to realize an antenna created by the optimization process shown in FIGS. **5** and **6**.

FIG. **23** is a graph of the performance of the switched aperture antenna in FIG. **22**.

FIG. **24** is a graph of the H-plane radiation pattern of the switched aperture antenna in FIG. **22**.

FIG. **25** is a diagram of a switched aperture antenna as in FIG. **21** for a 1.4 to 1.8 GHz frequency range for 30 degree steering.

FIG. **26** is a graph of the measured system gain as a function of frequency for the antenna in FIG. **25**.

FIG. **27** is a graph of the H-plane radiation pattern for the antenna in FIG. **25** that is steered toward 30 degrees from broadside.

FIG. **28** is a graph of three potential system gains for the switched aperture antenna in FIG. **22**, FIG. **25** and a third configuration not shown.

FIG. **29** is a diagram of a connected array of switched aperture antennas as shown in FIG. **22** to create a large configurable aperture.

FIG. **30** is a fragmented aperture antenna created by the optimization process described in FIGS. **5** and **6** realized through screen printing techniques.

FIG. **31** is a diagram of a computer that may implement the optimization process as shown in FIGS. **5** and **6**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** is a diagram of an antenna design structure **10** involving pattern structures of conducting and substantially non-conducting elements **11, 13** and utilizing the notion of percolation physics. Dark regions **11** represent conducting material while light regions **13** represent substantially non-conducting material. Conducting material may be any material that has a higher conductivity than the substantially non-conducting material. As a non-limiting example, the conducting material may be a material with semi-conducting qualities, and the substantially non-conducting material may be any type of dielectric material.

Each site that is occupied by conducting material **11** has probability, p_c. When p_c approaches a critical value, the percolation threshold, long chains **14** are likely to be formed in the structure **10**. For occupation probabilities greater than this threshold, there will be a continuous chain across the structure enabling direct current (DC) conduction to occur.

Near the percolation threshold, conducting chains **14** are created having a variety of lengths. These chains resonate at a wide range of frequencies and cause the structure **10** to have a broadband response. FIG. **2** is a graphical diagram **16** depicting the phase of the plane wave transmission coefficient **18** for the antenna design **10** (FIG. **1**) compared to that of a homogenous dielectric sheet **19**. The transmission phase response **18** of the percolating structure **10** is relatively flat across a wide frequency band. In contrast, the homogenous material **19** exhibits a linear phase variation with frequency. The flat transmission phase **18** of the percolating structure **10** is a result of the wide variety of length scales represented in the structure **10**. Thus, this structure **10** is useful as a broadband antenna and is hereinafter referred to as a fragmented aperture antenna.

FIG. **3** is a diagram of a fragmented aperture antenna **20**, as a non-limiting example, optimized to operate from 800 MHz to 2.5 GHz with flat 6 dB system gain. Antenna **20** is a square planar aperture of side length 10 inches and includes conducting structures arranged in isolation **22** and in patches **24**. The conducting structures are arranged in a grid wherein groups of the structures create the conducting patches **24**.

To use the pattern structure **20** as shown in FIG. **3** as an antenna, the energy gets out of the structure **20** through one or more feed points. It is desirable, however, to have as few feed points as possible. In one embodiment, feed points may be added to a fixed pattern after determining possible locations that would serve as good locations for the feed points. Criteria for placement of feed points may include places of high current flow. In the preferred embodiment, feed points may be placed in a fixed position and different antenna patterns may be configured to reach the desired performance.

One non-limiting example of the preferred embodiment for designing a fragmented aperture antenna is to place a feed **21** at the center of a 10 inch aperture and search for patterns that yield the desired antenna performance. In this embodiment, the antenna **20** is fed by a single, centrally located transmission line **21** of characteristic impedance 100 Ohms. Quadrant symmetry of the pattern **20*a***, **20*b***, **20*c***, **20*d*** is assumed so that linear polarization results in the direction broadside to the aperture. The conducting element size is chosen so that a 31×31 array fits within each quadrant **20*a***, **20*b***, **20*c***, **20*d***. Numerous random selected patterns are then evaluated for broadside gain as a function of frequency. This random search results in some suitable antennas; however, a more optimized search strategy is required.

This preferred embodiment of the invention implements a multi-stage optimization approach to design the fragmented aperture antennas, such as antenna **20** in FIG. **3**. In designing the antenna **20**, the objective is to obtain the maximum system gain in the broadside direction over a specified, relatively wide bandwidth. System gain includes any loss due to impedance mismatch. The antenna **20** is assumed to have reflection symmetry about two orthogonal planes. Additionally, the radiating structure of the antenna **20** is optimized using a modified genetic algorithm approach. Each quadrant (i.e., **20*a***) of the antenna **20** is a lattice of 31×31 square patches wherein each patch on the dielectric substrate can either be metallic or non-metallic. Thus, each quadrant **20*a*–20*d*** has 961 degrees of freedom ($2^{961}=10^{289}$ possible antennas). A direct genetic optimization with **961** binary genes exhibits very poor convergence as it is impractical to use a genetic algorithm directly in this 961 bit space because of computational requirements.

Implementing a two-step process, however, improves the convergence rate. The first stage implements a direct genetic optimization using a large-scale characterization of the antenna aperture **20**—typically 40 genes. The second stage is a stochastic hill climb optimization using the fine scale characterization—961 degrees of freedom for a typical 31×31 aperture (which is one quadrant (i.e., **20*a***) of the antenna aperture **20**). Briefly described, a simple stochastic hill climb consists first selecting a location in the aperture $$$at random. The bit at this location is toggled—in effect changing this location from free space to metal or metal to free space. This candidate antenna is evaluated. If the antenna is better than the previous antenna, then this change is retained. Otherwise, the antenna is returned to its previous state. This process is repeated many times until the rate of improvements practically stops. Alternatively, a genetic algorithm method similar to that as disclosed in U.S. Pat. No. 5,719,794, which discloses a method for designing wire antenna configurations and is herein incorporated by reference, may be implemented for design of fragmented aperture antennas. Moreover, other advanced hill climb procedures may also be used. These advanced methods include selecting multiple locations in the aperture and/or changing more than a single bit. Nevertheless, the stochastic hill climb is a random walk toward a more optimal antenna. This two-step approach exhibits acceptable rates of convergence and is described in more detail hereinafter.

The first stage of optimization process, to obtain a uniform antenna system gain over a desired frequency range, requires a description of potential antennas with a smaller number of binary digits than the full 961 required for the 31×31 aperture. FIG. **4** is a diagram of a set of trapezoidal conducting strips **30** arranged in fixed locations to provide a coarse description of the antenna **20** ultimately developed as shown in FIG. **3**. The coarse description of the antenna composed of the conducting strips is comprised of four quadrants **20*a***, **20*b***, **20*c***, **20*d***. With additional reference to the flowchart **40** in FIGS. **5** and **6**, which show the two-step optimization process, a set of trapezoidal conducting strips are arranged in fixed locations in a quadrant (i.e., **20*b*** (FIG. **4**)) to provide a coarse description of the antenna **20** (FIG. **3**), as in step **41**. Binary genes describe the length of two opposite sides of the trapezoids **30** (FIG. **4**), so that the conducting strip could be, for example, a triangular region **31** (FIG. **4**) (one side equal to zero), a rectangular region **32** (FIG. **4**) (both sides equal), a general trapezoid **34** (FIG. **4**) (unequal but non-zero sides) or non-present **36** (FIG. **4**) (both sides equal to zero). The term binary genes represents genes that consist of a series of bits; for example, a gene that consists of 5 bits has $2^5 = 32$possible states. In the non-limiting example, the length of a side **38** may be represented as 32 possible lengths (between 0 to 31); therefore, five bits are needed in this non-limiting example to prescribe a given strip, as described in step **43**. In this embodiment, a typical antenna may contain 10 to 20 strips, so a total of 50 to 100 bits describes the antenna for the first stage of the optimization process, as shown in step **45**.

Once the genetic optimization is performed using the large-scale description of the aperture distribution as described above, a fine-scale optimization process is performed, as in step **47**. This process uses the full description of the antenna (961 bits for the 31×31 aperture). The fine-scale optimization process makes a minor modification to the antenna design and then compares the performance of the new antenna to that of the genetically optimized antenna. A random location in the antenna is selected, as in step **48**, and a determination is made of whether the site contains a conductor, as in step **49**. If the selected site contains a conductor **22** (FIG. **3**), as in step **51**, the conductor is removed and the performance of the resulting antenna is computed, as in step **53**. If the site did not originally contain a conductor **22** (FIG. **3**), as in step **54**, one is added and the performance is likewise computed, as in step **53**. If, as in step **56**, it is determined that the new antenna performs better than the initial antenna, it is kept, as in step **58**. Otherwise, as in step **59**, the initial antenna is retained if a determination is made in step **56** that the initial antenna outperforms the resulting antenna. The optimization process may be repeated as many times as desired or until no further improvements are found, as shown in step **60**. Ultimately, a final antenna design is rendered, as in step **62**. This procedure can dramatically change the appearance of the conductor distribution in the aperture and typically results in a 3 dB improvement in the antenna performance.

FIG. **7** is a diagram of the predicted and measured performance **64** of the antenna radiating structure **20** in FIG. **3** that was optimized using the two-stage process described above to yield the best broadside system gain over the frequency span of 800 MHz to 2.5 GHz. System gain **65** is defined as directive gain times mismatch. Directive gain is the ideal gain of the antenna that is in the direction of maximum radiation, and mismatch accounts for the difference between the load impedance and the generator impedance of the communicating system. Because the optimization includes the effect of mismatch, the Voltage Standing Wave Ratio (VSWR) of the designed antenna is directly constrained. Thus, the measured system gain **65** for the antenna **20** is compared with the design prediction **67** for the same antenna. Predicted results **67** are generated using a numerical code based on the Finite-Difference Time-Domain (FDTD) Method.

Additionally, the system gain **65** is seen to be relatively flat across the frequency region that extends beyond the design bandwidth at the high end. Line **68** represents the directivity of an aperture of the same area with a uniform distribution of current, and line **69** represents the gain of a spiral antenna (not shown). Since the optimization process attempts to achieve a flat gain, the result is limited by the lowest frequency in the band of operation as evidenced by the fact that the system gain **65** is fixed to be the same as the directivity of the uniform current **68** at the lower end of this specified frequency range. Thus, it is desirable to search for designs whose gain over frequency attempts to mimic the uniform aperture gain **68** instead of a flat gain as evidenced by the measured system gain **65**.

FIG. **8** depicts graph **70** which is the measured H-plane radiation pattern **71** of antenna **20** (FIG. **3**) compared to the design prediction **72**. As corroboration to the graph of antenna **20** in FIG. **7**, the radiation pattern **71** is directed in the broadside direction as designed.

FIG. **9** is a diagram of a fragmented aperture antenna **75** optimized over a 0.4–2.04 GHz frequency range to achieve a system gain that follows the uniform aperture limit. Antenna **75** is fed centrally by feed **76** and is quadrantly symmetrical similarly to antenna **20** in FIG. **3**. Antenna **75** is a result of the two-step optimization process as described above, and as shown in FIGS. **5** and **6**.

FIG. **10** is a graph **80** of the predicted performance of antenna **75** in FIG. **9** showing the directive gain **77**, system mismatch gain **78** and uniform aperture gain **79**. The system mismatch gain **78** tracks the uniform aperture limit **79** within a few dB over the optimization range. As evidenced from the fragmented aperture antenna **75** in FIG. **9**, the genetic algorithm placed metal conductors near the top and bottom edges of the aperture **75** in an attempt to use the full aperture to enhance the low-frequency performance. The directive gain **77** is shown in FIG. **10** which factors out mismatch loss of the antenna **75**. Over most of the frequency region, the directive **77** and system mismatch gains **78** are almost identical, indicating a good impedance match for the antenna. However, the peak in the directive gain **77** at 1 GHz shows how the optimization process allowed a larger mismatch loss at a point where it could achieve a higher directive gain **77**.

FIG. **11** is a diagram of a fragmented aperture antenna **81** optimized over a 1.4–1.8 GHz frequency range to achieve a system gain that follows the uniform aperture limit. Antenna **81** is fed centrally by feed **82** and is quadrantly symmetrical. The frequency design is 1.3:1 to cover the 1.4–1.8 GHz frequency range.

FIG. **12** is a graph **83** of the performance for the antenna **81** as displayed in FIG. **11**. For antenna **81**, the system gain **84** in the broadside direction is very close to the uniform aperture limit **86**. The antenna **81** (FIG. **11**) is well matched over the design bandwidth as evidenced by the system and directive gains **84**, **87** being essentially the same. As evidenced by graph **83**, the antenna performance falls off rapidly outside the optimization region.

The exemplar antenna designs **20**, **75**, **81** (FIGS. **3**, **9** and **11**) are all linearly polarized. The optimization process described above in FIGS. **5** and **6** may also be implemented to design a dual polarized antenna with a separate feed point for two linear polarizations. FIG. **13** is a non-limiting example of a fragmented aperture antenna **90** optimized for dual polarization over a 1.4–1.8 GHz frequency range. There are two sets of feed points (not shown) located in the center of the aperture. One set is oriented vertically and the other set is oriented horizontally. The two pairs form a cross shape. FIG. **14** is a graph **92** of the predicted performance of the antenna **90** displayed in FIG. **13**. The broadside system and directed gains **91**, **93**, as shown in FIG. **14**, both follow the uniform aperture limit **95**.

The planar antennas discussed above naturally radiate equally in both broadside directions. For some applications, the backward radiation can be detrimental to the performance of the antenna. Scattering from supporting hardware behind the antenna can significantly influence the antenna performance in an unpredictable manner. As a non-limiting example, an antenna near a human body incurs electromagnetic loss because the body reduces the efficiency. Thus, a ground plane can be used to reduce the radiation in the backward direction and help alleviate this problem. For a narrow band antenna, this can simply be accomplished by placing a metallic conductor at $\lambda/4$ behind the antenna. The energy reflected from the ground plane adds constructively with the direct radiation to enhance the gain by 3 dB (for the ideal case of a ground plane infinite in an extent). However, as the bandwidth of the antenna increases, this solution does not always apply.

In an alternative embodiment, a broadband ground plane is created by using a similar optimization strategy as described above in FIGS. **5** and **6** in regard to the design of a fragmented ground plane. The fragmented ground plane is a second patterned sheet placed behind the radiating layer to reflect the energy in the forward direction. FIG. **15** is a diagram of an antenna system **98** including antenna **100** with a fragmented ground plane **99**. The fragmented ground plane **99** is a patterned layer similar to the radiating aperture **100** and is designed to operate as a ground plane over the bandwidth of the radiating aperture **100**. Feed **101** is applied to the radiating aperture **100** and the ground plane layer **99** is placed in parallel to the radiating aperture **100** at a distance of $\lambda/8$ at the highest frequency. Ground plane **99** is designed after the radiating aperture **100** is created to simplify the optimization process.

FIG. **16** is a diagram of two separate ground plane layers **105**, **106** designed for the same radiating aperture **108**. The ground plane **105** used the structure of the radiating aperture

108 as the starting point for the optimization process as described above which utilizes the stochastic hill climb method. The ground plane **106** was created through the optimization process described above and shown in FIGS. **5** and **6** based upon a solid metal sheet (not shown) as the starting point. While the ground plane layer structures **105**, **106** are different, the results yielded by the ground planes are similar.

FIG. **17** is a graph diagram **104** of the performance of the fragmented aperture **108** with ground plane layers **105**, **106** as compared to the uniform aperture limit **111**. The addition of either ground plane layer **105**, **106** (FIG. **16**) yields approximately 2.1–2.2 dB of improvement in the broadside gain **112**, **114** of the antenna **108**. As a comparison, line **116** is based on the performance of antenna **108** with no ground plane layer at all. There is, however, a slight increase in mismatch when the ground plane is added since the directivity actually improves by approximately 3 dB.

FIG. **18** is a graph diagram **120** of the measured performance of the fragmented aperture antenna **108** with ground plane **105** (FIG. **16**) to show performance improvement. Line **121** represents the performance measurement of the antenna with the ground plane **105**, and line **123** represents the performance measurement of the antenna without any ground plane. The measured results show the 2 dB of improvement with the fragmented ground plane **105**. The result of including the ground plane layer **105** is a significant reduction in the radiation in the backward direction as evidenced by the horizontal pattern **124** in FIG. **18**. In this diagram, the radiation pattern of the antenna with the ground plane layer **105** is represented by line **125**, and the radiation pattern of the antenna without any ground plane layer is represented by line **126**.

The single fragmented aperture antenna as described above may also be placed in an array of multiple antenna elements. In one embodiment, the fragmented aperture antennas configured in the array environment are allowed, through the optimization process, to physically touch neighboring antenna elements, thereby creating a connected array. FIG. **19** is a diagram of three fragmented aperture antennas similar to the antenna shown in FIG. **3** arranged in a connected antenna array **130**. To create the connected antenna array **130** in FIG. **19**, a suitable antenna element is selected (based on bandwidth, gain, VWSR) and then the spacing and size are chosen such that no grating lobes exist and that the required array gain is met. The performance of the selected antenna array **130** is slightly modified by the presence of the neighboring antennas **131***a*, **131***b*, **131***c* (mutual coupling terms are small or manageable). In the connected array, the antenna elements **131***a*, **131***b*, **131***c* may physically touch, so the embedded array behavior does not resemble the isolated antenna behavior. By allowing the antenna elements **131***a*, **131***b*, **131***c* to touch, the low frequency limit of operation is not set by the size of the isolated elements, but rather, it is set by the size of the array antenna **130**.

In focusing on the antenna array **130** in FIG. **19**, as a non-limiting example, an array spacing of ten inches allows broadside operation up to approximately 1.2 GHz before the potential appearance of grating lobes. A traditional wideband antenna, such as an 8-inch bow-tie, will operate down to 250 MHz. The connected array elements **130**, as in the non-limiting example in FIG. **19**, are optimized to operate from 100 MHz to 1 GHz. The same two-step optimization approach discussed above and as shown in FIGS. **5** and **6** produces the antenna array **130** as shown in FIG. **19**. The genetic design approach does not necessarily force the elements **131***a*, **131***b*, **131***c* to be connected; however, as evidenced in FIG. **19**, the elements **131***a*, **131***b*, **131***c* are, in fact, connected.

FIG. **20** is a graph **135** of the performance of the antenna array **130** shown in FIG. **19**. The system mismatch gain **137** for the antenna array **130** is acceptable over the 100 MHz to 1 GHz frequency span, i.e., the performance tracks the uniform stick directivity **138**. The performance of a comparable bow-tie antenna array is shown by line **139**, and the directive gain of the antenna array is line **140**. The performance of the connected array **130** is approximately 10 dB superior at the low frequency as compared to the performance of the bow-tie **139**. The bow-tie antenna frequency drops out at 0.6 GHz, but this drop out is not present in the results of the connected antenna array **130**, as shown by line **137**. Finally, because the system gain **137** tracks the uniform stick directivity **138** closely, the diffraction-limited performance is achieved to below 100 MHz.

The discussion above in regard to fragmented aperture antennas illustrates the construction of aperture patterns that yield optimized performance over selected frequency bands. Another embodiment of the invention is herein discussed which realizes a reconfigurable aperture and achieves multiple fragmented aperture designs from a single aperture. The reconfigurable aperture offers the potential for wideband antenna designs.

FIG. **21** is a diagram of a switched aperture antenna element **143**. The switched aperture antenna **143** includes a centrally located feed point **149** to transfer energy from the antenna. The antenna aperture **143** consists of a lattice of conducting patches **145** that are electrically small (approximately 1/20wave length) and connected by switches **147**. The switches are opened **147***a* and closed **147***b* to configure the antenna **143**. As a non-limiting example, conducting patch **145***a* is connected to neighboring connected patch **145***b* by switch **147***b*'. The configured antenna **143**, in this non-limiting example, is similar to a traditional bow-tie antenna as shown by dashed lines **146**. The switches **147** can be realized by using MEMS (Micro-Electromechanical Systems) devices, PIN diodes, latches, radio frequency (RF) transistors, or other similar devices known to those of ordinary skill in the art.

The switched aperture antenna **143** in FIG. **21** can be configured to realize optimized patterns arranged to operate over specific bands of frequency and directions of radiation. The expected performance of these designs should approach the levels achieved by the optimized fractured aperture antennas discussed above. In the preferred embodiment, the size of the aperture **143** is fixed to ten inches square, and the size of the individual metal patches **145** and switches **147***a*, **147***b* are four millimeters square.

FIG. **22** is a switched aperture antenna **150** with the several switches **152** closed to realize an antenna created by the optimization process described above. This non-limiting aperture design **150** is configured to radiate broadside to have the best system gain over 1.4 to 1.8 GHz frequency range. Metal patches **154** are connected by closed switches **152** while open switches **155** are shown as blank space. Feed point **156** is connected at the center of the array **150**. FIG. **23** is a graph **160** of the performance of the switched aperture antenna **150** as configured in FIG. **22**. The system gain **162** of the switched aperture antenna **150** is shown in FIG. **23** as a function of frequency. The system gain **162** tracks the uniform aperture gain **164** closely over the 1.4 to 1.8 GHz optimization range, and is within 1 dB of this limit **164**. The broadside gain is shown as line **166**. As a result, the performance of the antenna array **150** in FIG. **22** is nearly diffraction limited. The H-plane radiation pattern **170** is shown in FIG. **24**. The measured radiation pattern **172** is directed in the broadside direction as desired based upon the model pattern **174**.

A switched aperture antenna configuration may also be designed to radiate at, as a non-limiting example, 30 degrees from broadside with a system gain over the 1.4 to 1.8 GHz frequency range. FIG. **25** is a diagram of a switched aperture antenna **180** for over a 1.4 to 1.8 GHz frequency range for 30 degree steering. As compared to the switched aperture **150** in FIG. **22**, switches **181** are configured in a non-symmetrical arrangement to achieve the beam steering in the configuration that connects the conducting patches **183**. The measured system gain **188** as a function of frequency is shown in the graph **185** of FIG. **26**. The measured system gain **188** closely follows the predicted gain **192**. The measured system gain **188** tracks the uniform aperture limit **190** over the 1.4 to 1.8 GHz optimization range. The H-plane radiation pattern **197** is shown in graph **195** in FIG. **27** and is clearly steered toward 30 degrees from broadside. As a result, the measured system gain **188** (FIG. **26**) and H-plane radiation pattern **197** conform to the design predictions **198** based on the optimization procedure described above.

FIG. **28** is a graph diagram **200** of three system gains **202**, **204**, **206** for the switched aperture antenna **150** (FIG. **22**), **180** (FIG. **25**) and a third antenna optimized for a 2.4–3.0 GHz range (not shown). Thus, by arranging the switches of a switched aperture antenna in multiple configurations, the antenna can be modified to perform to different characteristics and still approach the uniform aperture gain limit **208** for different frequency ranges.

Switched aperture antennas may also be constructed in a connected array such that a large configurable aperture is comprised of an array of identically smaller, reconfigurable elements as shown in FIG. **29**. The fragmented aperture array structure **210** is a connected array similar to the connected non-switched arrays as discussed above. Metal patches **211** are connected by closed switches **213** to form the antenna array **210**. Each of the antenna elements **210***a*–**210***f* are fed by feed patches **215**. In the fragmented aperture array **210**, the antenna elements **210***a*–**210***f* in the array may physically touch; hence, the embedded array behavior does not resemble the isolated antenna behavior. By allowing the elements **210***a*–**210***f* to touch, the lower frequency limit of operation is not set by the size of the isolated element, but rather it is set by the size of antenna array. Thus, one configuration of a configurable array can operate broadband for a particular set of beam widths and steering angles, and the configuration of each array element can be changed from different beam widths and steering angles. Such an architecture has a significant cost reduction savings due to the repeated fabrication of a small pattern of patches and switches.

Antennas that can be described as 2-dimensional structures can be considered planar antennas. These antennas, if flexible, can also be considered conformal antennas, that is, they can be molded around objects and made to conform to the surface of the underlying structure. The type of antennas designed and fabricated as part of the screen printing subtask are all planar, conformal antennas.

Screen printing (also known as silk screen printing) is a process whereby ink is forced through tiny holes in a screen onto a substrate. The areas of the screen where one does not want inks coming through are covered with a solid epoxy. The ink dries and an image is bonded to the surface of the substrate. To create an antenna by screen printing techniques, the process may implement, as a non-limiting example, conductive inks containing silver particles or, as another non-limiting example, resistive inks containing carbon particles. Antenna ground planes may also be fabricated using the same inks.

FIG. **30** is a fragmented aperture antenna **220** created by the optimization process described above and realized through screen printing techniques. Substrates such as Kapton, Tyvek, Polyester, and Mylar may be used as material receptive to the screen printing of the antenna. Feed **222** is centrally located similarly as described above. Antennas created by the optimization process described above in FIGS. **5** and **6** may be printed on these substrates for performances shown in the previous figures.

Any process descriptions or blocks in flow charts should be understood as representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions or steps in the process, and alternate implementations are included within the scope of the preferred embodiment of the present invention in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present invention.

The optimization process, as discussed above in relation to FIGS. **5** and **6**, comprises an ordered listing of executable instructions for implementing logical functions, can be embodied in any computer-readable medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a "computer-readable medium" can be any means that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The computer readable medium can be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples (a nonexhaustive list) of the computer-readable medium would include the following: an electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a random access memory (RAM) (electronic), a read-only memory (ROM) (electronic), an erasable programmable read-only memory (EPROM or Flash memory) (electronic), an optical fiber (optical), and a portable compact disc read-only memory (CDROM) (optical). Note that the computer-readable medium could even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via for instance optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in a computer memory.

The optimization process as discussed above and as shown in FIGS. **5** and **6** may be implemented on a computer. FIG. **31** is a diagram of a computer **230** that may be utilized to implement the optimized process as shown in FIGS. **5** and **6**. Housing **232** contains a processor **234** that accesses memory **236** via local interface bus **238**. The memory **236** may store software **240** and other data **241**. A monitor **243** is coupled by a video interface **245** to the bus **238** for presenting a display to the user. One or more input interface cards **247** may be coupled between the bus **238** and a keyboard **249**, mouse **250**, a microphone **252** and/or a scanner **253**. The processor **234** may communicate with an external network **260** by a modem **261**. An output interface card **264** may also be coupled to the local interface bus **238** for outputting audio to a speaker **266** and for outputting other data to a printer **267**. A mobile data storage device **270** may be included in computer **230** and is coupled to the local interface bus **238**.

It should be emphasized that the above-described embodiments of the present invention, particularly, any "preferred" embodiments, are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the invention. Many variations and modifications may be made to the above-described embodiment(s) of the invention without departing substantially from the spirit and principles of the invention. All such modifications and variations are intended to be included herein within the scope of this disclosure and the present invention and protected by the following claims.

At least the following is claimed:

1. An antenna, comprising:

a planar layer having a plurality of first areas and a plurality of second areas, said first areas being more conductive than said second areas;

wherein each area has a periphery that extends along a grid of first and second sets of parallel lines so that each area comprises one or more contiguous elements defined by said lines; and

wherein said first and second areas are configured and arranged so that said planar layer can communicate electromagnetic energy wirelessly in a specific direction to said planar layer when an electrical connection is made to at least one of said first areas.

2. The antenna of claim **1**, wherein said first and second sets of parallel lines are orthogonal, said elements are squares, and each said area is a square, rectangle, or geometric region having orthogonally diverging contiguous segments.

3. The antenna of claim **1**, wherein said first areas comprise a conductive or semiconductive material and said second areas comprise a dielectric or semiconductive material.

4. The antenna of claim **1**, further comprising a switch capable of electrically coupling at least two of said first areas.

5. The antenna of claim **4**, wherein the switch is a micro-electromechanical switch.

6. The antenna of claim **4**, wherein the switch is a PIN diode.

7. The antenna of claim **4**, wherein the switch is a radio frequency (RF) transistor.

8. The antenna of claim **4**, wherein the switch is a latch switch.

9. The antenna of claim **4**, wherein the antenna can be configured to realize optimized patterns arranged to operate over specific bands of frequency and directions of radiation.

10. The antenna of claim **1**, further comprising one or more other planar layers serving as a ground plane and situated substantially parallel to said planar layer that communicates said electromagnetic energy.

11. The antenna of claim **10**, wherein one or more of said other planar layers comprises pluralities of said first and second areas.

12. The antenna of claim **10**, further comprising a switch capable of electrically coupling at least two of said first areas of said other planar layers.

13. The antenna of claim **1**, further comprising one or more other planar layers situated adjacent to and substantially in the same plane as said planar layer so that said layers together can operate as an antenna array.

14. The antenna of claim **13**, wherein the size and spacing of the antenna array is selected to reduce grating lobes.

15. The antenna of claim **1**, wherein said first and second areas of said planar layer are symmetric about each of two orthogonal lines situated in the plane of said planar layer.

16. A method for making an antenna, comprising the steps of:

defining a planar grid defined by first and second sets of parallel lines so that the grid comprises a plurality of elements defined by the lines; and

determining a first plurality of said elements that should be substantially conductive and a second plurality of said elements that should be substantially nonconductive so that a hypothetical antenna formed from said planar grid elements exhibits a desired frequency spectrum.

17. The method of claim **16**, further comprising the steps of:

dividing said grid into a plurality of areas;

performing said determining step for one of said areas to derive a pattern of elements for said area; and

replicating said pattern in other areas.

18. The method of claim **16**, further comprising the step of utilizing a genetic code to perform said determining step.

19. The method of claim **18**, further comprising the step of simulating the electromagnetic characteristics of said, antenna with a genetic sequence program.

20. The method of claim **16**, further comprising the step of defining an antenna comprising:

a planar layer having a plurality of substantially conductive areas and a plurality of substantially nonconductive areas;

wherein each area has a periphery that extends along said grid so that each area comprises one or more of said elements defined by said lines; and

wherein said areas are configured and arranged so that said planar layer can communicate electromagnetic energy wirelessly in a specific direction to said planar layer when an electrical connection is made to at least one of said conductive areas.

21. The method of claim **20**, further comprising the step of evaluating an effect on said frequency spectrum of one or more other planar layers serving as a ground plane and situated substantially parallel to said planar layer that communicates said electromagnetic energy.

22. The method of claim **21**, further comprising the step of evaluating an effect on said frequency spectrum of a switch capable of electrically coupling at least two elements of said other planar layers.

23. The method of claim **20**, further comprising the step of evaluating an effect on said frequency spectrum of one or more other planar layers situated adjacent to and substantially in the same plane as said planar layer so that said layers together serve as an antenna array.

24. The method of claim **16**, further comprising the steps of:

representing said elements of said grid with a set of bit values;

mapping a geometric shape having an area greater than one of said elements across said grid;

defining said bit values based upon said mapping; and

performing said determining step based upon said bit values.

25. The method of claim **16**, wherein said first and second sets of parallel lines are orthogonal and said elements are squares.

26. The method of claim **16**, further comprising the step of defining areas with said elements, each said area being a square, rectangle, or geometric region having orthogonally diverging contiguous segments.

27. The method of claim **16**, further comprising the step of evaluating an effect on said frequency spectrum of a switch capable of electrically coupling at least two of said conductive elements.

28. The method of claim **16**, wherein said conductive and nonconductive elements are symmetric about each of two orthogonal lines situated in the plane of said grid.

29. The antenna of claim **16**, wherein the substantially conductive element is conductive ink containing silver particles arranged on a substrate.

30. The antenna of claim **16**, wherein the substantially conductive element is resistive ink containing carbon particles arranged on a substrate.

31. The antenna of claim **16**, wherein the planar grid is flexible so that it can be molded to conform to the shape of three dimensional objects.

32. An antenna made by the process of:

arranging a plurality of conducting strips in an optimized sequence according to desired performance quality for said antenna; and

modifying conductor configuration at one or more randomly selected locations on said antenna until said antenna acquires said desired performance quality.

33. The antenna of claim **32**, wherein a conductor is removed if said location contains a conductor, wherein a conductor is inserted if no conductor is contained in said location.

34. A two-stage process to synthesize a design of a fragmented aperture antenna in three dimensions using a computer, the process comprising the steps of:

loading a computer with a genetic algorithm model and an electromagnetic code, the genetic algorithm model being a preselected set of permutations of alternative geometric configuration possibilities for a fragmented aperture antenna within a three-dimensional volume and wherein the electromagnetic code is a correlation model that correlates fragmented aperture antenna prospectives from genetic antenna configurations;

specifying to the computer a desired set of electromagnetic antenna element properties;

directing the computer to identify a first set of fragmented aperture antenna designs from the fragmented aperture antenna prospectives by testing the preselected set of permutations proposed by the genetic algorithm using in three dimensions the electromagnetic code;

directing the computer to identify a final set of fragmented aperture antenna designs from the first set of fragmented aperture antenna designs by testing the first set of fragmented aperture antenna designs by the genetic algorithm using in three dimensions the electromagnetic code;

selecting a fragmented aperture antenna design from the final set of fragmented aperture antenna designs; and

wherein the fragmented aperture antenna is quadrantly symmetrical with a centrally located transmission feed line.

35. A process to synthesize a design of a printed fragmented aperture antenna in three dimensions using a computer, said process comprising the following steps:

loading an algorithm comprising a space of possible solutions represented by some representational scheme which, by some iterative process, will converge to an optimal solution, to be used in conjunction with an electromagnetic code onto a computer;

specifying a desired set of electromagnetic properties for the fragmented aperture antenna element to be designed;

defining size, geometry and/or features of said fragmented aperture antenna;

specifying a sample population size to be randomly or otherwise selected from among all possible fragmented aperture antenna configurations based upon said size, geometry, and/or features of said fragmented aperture antenna;

computing electromagnetic properties of a plurality of conducting and non-conducting elements in each fragmented aperture antenna configuration in three dimensions in the sample population using the electromagnetic code and rank solutions in order of performance, wherein the fragmented aperture antenna comprises a centrally located transmission feed;

modifying the population by a method that brings the population incrementally closer to an optimum solution;

repeating this iterative process a specified number of generations or until the population fitness reaches equilibrium which is considered an optimal solution.

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